Novice Programmers Strategies for Online Resource Use and Their Impact on Source Code

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Abstract—Websites are frequently used by programmers to support the development process. This paper investigates programmer-Web interactions when coding, and combines observations of behaviour with assessments of the resulting source code. We report on an online observational study with ten undergraduate student programmers as they engaged in programming tasks of varying complexity. Screens were recorded of participants' activities, and each participated in an interview. Videos and interviews were thematically analysed. Novice programmers employed various strategies for seeking and utilising online knowledge. The resulting source code was examined to determine the extent to which it met requirements and whether it contained errors. The source code analysis revealed that coding with the websites involved more coding time and effort, but increased the possibility of producing correct code. However, coding with websites also introduced instances of either incorrect or non-executable source code.

Index Terms—Web Search, Knowledge reuse, Information Search and Retrieval, Software Engineering.

I. INTRODUCTION

The internet has made information more accessible than ever before, with significant implications for how people learn and practice programming. Website usage is viewed as an integral part of the software engineering process [1]. Developers sometimes spend more time searching for information online than coding, assisting their learning and clarifying terms [2].

Searching is considered a vital process that is conducted pervasively to augment programmers' knowledge, even for familiar issues [3, 4, 5, 6]. In addition to providing information, searching the websites also aids in code understanding and error correction [2, 7]. Programmers repeatedly access previously visited Web pages [8]. However, searching can affect programmers' productivity, as using the websites for simple tasks can take more time than coding from scratch, and searches may not always be successful [9]. It can be difficult for programmers to locate and assess online code snippets [10], which are often of low-quality [11]. Students, in particular, experience challenges, given their lack of vocabulary to assist their searches [12].

Seeking knowledge online is usually coupled with utilising code [13], providing a structural template and supporting similar functionalities [14]. Copying code from online sources is commonplace during development, especially from the

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website Stack Overflow[2, 11, 15, 16]. There is evidence that online queries are focused primarily on code reuse [17] and that increased complexity in source code leads to greater online information seeking [18]. To date, there has been little exploration of how seeking and utilising online knowledge affects the production of source code.

Online code is often of poor quality or unsuited to the task at hand, making it challenging to use effectively. Prior research shows that code snippets on Stack Overflow contain problematic code such as security issues [19, 20, 21] and outdated statements [22].

The current study documents how programmers use the websites to complete a series of coding tasks, and examines how these activities may affect the resulting source code. We screen recorded ten undergraduate students solving four programming tasks with varying levels of difficulty. We also collected the resulting source code for analysis and interviewed the programmers to understand in more depth why they used particular strategies and how these affected their code. Our research questions were as follows:

RQ1 How do programmers use websites during programming? RQ2 What are the effects of websites use on the resulting code?

Our results show that programmers use various strategies to seek and utilise online knowledge. These strategies may increase task completion time and effort but increases the chances of producing correct code. However, website use does not guarantee functional code – in several instances participants still fail to produce code that executes and/or meets requirements. The results of this study shed the light in coding with the websites with a unique approach applying multiple inputs of data to the investigation, as well as in the assessment of the resulting code to discover problematic code propagation.

II. RELATED WORK

Our work builds on research from software engineering that seeks to understand programmers' activities, and examines the resulting code to investigate possible implications.

A. Understanding coding activities

In computer science education, *learning analytics* such as Error Quotient [23, 24] and Watwin Score [25] (both based on compilation behaviour and errors), NPSM [26, 27] (based on a more holistic set of IDE-captured measures), and RED [28] (a measure of repeated errors), have been used to quantify programming behavior and predict outcomes. Outside of teaching, IDE instrumentation has been used to identify problem solving strategies [29] and code/documentation interaction patterns [9, 18] (e.g. investigate, edit, validate [30]).

Qualitative approaches are also used to characterise programmer behaviours [9, 10, 12, 31, 32, 33, 34, 35, 36]. For example, Ko *et al.* analysed screen captures for experts engaging in software maintenance tasks, identifying three common activities – code search, dependency following, and code collection [34]. Combining IDE instrumentation with surveys and interviews has been used to understand professionals' debugging activities, with printf and breakpoints used in preference to more advanced IDE functionality [37]; interviews have also been used to understanding student debugging [35].

Whilst the above focus on in-editor activity, this study seeks to better understand the usage of websites during coding activities. Such behaviors have previously been observed by Han *et al.*, who combined eye-tracking with IDE and browser logs to capture behaviour in Python tasks. In addition to quantifying code production, their study identifies patterns of external resource use (e.g. searching, copy-paste) [38].

1) Search: Programmers use their coworkers for information [36], and search both within their own codebases [4, 6, 34, 39, 40, 41] and for online information (e.g. through Google's Web search) [2, 5, 19, 38, 39, 42, 43]. In this paper, we focus on the interactions when coding with websites, and our discussion of search therefore centers on this latter behavior. Google has been observed to dominate programming-related search, with the Stack Overflow Q&A website most prominent in results [10, 11, 12, 17, 19]. However, the behaviour of novices and students may differ, e.g. using search to identify online tutorials in preference to Stack Overflow [2, 42, 44].

Search engines are used to support code comprehension and reuse [11, 17, 44, 45], debugging [7, 11, 17], information acquisition and reference [2, 7, 11, 17]. Search frequency increases when tasks become complex [18, 43], and both searches and their results are often consulted multiple times in a single session [8, 42]. For example, Astromskis *et al.* found low rates of search among professionals (6% of sessions), but observed intense online consultation during some sessions with more complex code leading to greater use of the websites [18].

Searching websites are not always (immediately) successful. In observations, Wang noted that some participants did not click any of the search results, or that viewing a website was immediately followed by new search behavior [9]. Other studies confirm that multiple queries may be needed to identify appropriate resources [8, 11, 12, 18]. This may be a result of difficulties representing code and symbols in queries; retrieval of unanswered questions; and retrieval of resources that are of poor quality, missing exemplars, or are difficult to understand [10, 11]. Effective search may be particularly problematic for novices, who lack strategies and vocabulary and have difficulty

assessing the relevance of results [5, 12, 32, 46]. However, professionals also report challenges, particularly with regard to the volume of information retrieved [33]. Finally, context-switches arising from search may themselves be problematic, reducing productivity [18].

2) *Code cloning/reuse:* A common objective for searching websites is the identification of code snippets for reuse [11, 13, 15, 16, 17, 46]. In one analysis of search queries, 46% were seeking code for reuse [17].

Studies indicate that both students [13, 47, 48, 49] and professionals [14, 18, 50, 51] engage in code cloning, although there is some evidence that students may adopt alternative approaches as they develop expertise [49]. Professionals report using code clones as a tool to help refactor code, act as a structural template/example, and support forks/branches [3, 14], and both groups engage in follow-on modification activity, e.g.: complete or partial removal, correction and compilation cycles, modification and 'beautification' to fit context, and addition of new code [5, 8, 47, 50, 52].

B. Impact on code

The prevalence of code cloning [11, 17] has led researchers to investigate the degree to clones could propagate problematic code. Users of online code snippets report them to be outdated, incomplete, incorrect, poorly structured, verbose, lacking meaningful variable names and rationale, and indicate that code often does not address their problems [22, 53, 54, 55]. These problems have also been identified in data mining studies [22, 56, 57, 58], and observation and lab studies suggest that use of websites typically leads to poorer code [19, 52].

Data mining has also been a valuable tool for measuring propagation [1, 20, 59]. Abdalkareem *et al.* examined 1, 496 Android apps finding that 377 had source in common with Stack Overflow, and the introduction of this code increased the number of subsequent bug fixes [59]. Propagation of security vulnerabilities is a particular concern. Lab study has shown that Stack Overflow users produce functional but insecure code [19], and data mining shows that a very high proportion of security-related snippets contain potential vulnerabilities [20], even in accepted answers, up-voted answers and answers from high reputation users [21]. However, not all studies agree that cloning is problematic – in a study of 1,244 open-source projects, code reuse predicted neither the presence or absence of security vulnerabilities [60].

Novice programmers may be particularly likely to generate and propagate problematic code. Static analysis of code written in an introductory programming exam identified both functional (syntax, logic) and stylistic errors [61].

In this paper, we provide in-depth qualitative analysis of novice programmers' online information-seeking and codecloning behaviours. Our research builds on knowledge from prior studies, using a combination of methods to provide a rich picture of online and in-editor activities, augmented with programmers' motivation and experiences of those activities, and the impact on code outputs.

III. METHODOLOGY

We conducted an online study in three sequential phases: a set of four video-captured programming tasks, source code collection, and then an interview (see Fig 1). This approach allows us to triangulate multiple data sources to build a rich understanding of our participants' behaviour [62].

The experiment was conducted with undergraduate students recruited from our university. Prior to recruitment, a pilot was used to ensure the clarity and validity of tasks, and to assess overall experiment duration. Procedures for the experiment were reviewed and approved by the Ethics Committee at our university All data was anonymized at time of collection.

A. Task design

This study phase required participants to engage in a number of programming tasks appropriate to the participants' experience and expertise. Having limited our recruitment to a single cohort of undergraduate students in their second year at our University, we could design our tasks to build on course materials from their first year of study. This included a course textbook [63], lecture slides, instructions for programming exercises, and sample solutions associated with those exercises. We extracted an initial set of thirty-three programming tasks from these materials.

To ensure task completion could be supported by online materials, specifically the Stack Overflow website¹, we conducted a preliminary search of Stack Overflow using task keywords. Tasks with fewer than twenty Stack Overflow answers were removed from the candidate pool, leaving fourteen tasks for further consideration. The remaining tasks were classified into three difficulty levels. Tasks that used only concepts/topics that were explicitly taught during the course unit lectures/exercises were classified as 'easy' (n=5), those that used a combination of explicitly taught and additional material (e.g. from the textbook) were classified as 'medium' (n=5), and those that required substantial additional material were classified as 'difficult' (n=4). From the classified tasks, we selected four tasks with a variety of difficulty levels: two easy, one medium and one difficult (See Table I).

B. Study Procedure

Our three-phase study took place over the Zoom video conferencing software, and using the Dropbox file hosting service.

1) Preliminaries: All participants were provided with a briefing sheet prior to participation (available as supplementary material²). A video call with each participant was initiated, and the researcher summarised the phases of the study. Once participants had a good understanding of the nature of their involvement, they were asked to provide verbal consent and recording of the call (audio and screen capture) commenced.

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2) Phase 1: Video-captured programming tasks: At the beginning of this phase, participants were presented with a document summarising the four programming tasks. Participants were instructed that they should not overly concern themselves with the need to correctly solve all tasks, and that they could use any of their usual software, resources, or websites during task completion. Participants were then asked to share their screen and could begin solving the tasks using their preferred IDE or editor.

During the programming tasks, the researcher muted their mic and turned off their own video camera so as to minimise distraction. The researcher did not intervene or interrupt the coding tasks unless participants directly requested that they did so (e.g. to help resolve a technical issues or task). The researcher did not provide any programming-related information that could help the participant solve tasks, even if requested to do so by the participant.

The programming task phase ended after 50 minutes of elapsed time, or earlier if a participant indicated that all four tasks had been completed. Upon completion, screen sharing and recording was stopped, and the resulting video files (one per task) were saved for subsequent analysis.

3) Phase 2: Source code collection: Participants were then requested to share their final set of source code files for the four programming tasks. Zoom chat was used to direct participants to a Dropbox upload link.

4) Phase 3: Interview: The final phase was an audiorecorded structured interview. Participants were asked to provide their age, gender and describe their programming expertise/experience. They were asked about their experiences of completing the programming tasks, and the degree to which their behavior was representative of the participant's usual programming activity. Participants were additionally asked targeted questions about their use of websites during typical programming and during the experiment's programming task phase, code cloning behaviours during the programming task phase, and the relationship between website-based information retrieval and existing knowledge (i.e. are they looking up things to refresh/jog their memory). The full questionset is provided in the supplementary material².

C. Participants and Recruitment

Our target population were invited to participate through emails (sent to all second year computer science students) sent by course directors. Ten participants (five males and five females, aged 19 - 22 years) responded and participated in the study (see Table II). Participants were compensated with a £10 GBP Amazon gift certificate³.

D. Analysis

Interview recordings were transcribed for analysis. We analysed interview (phase 3) transcripts first, and subsequently used the knowledge gained to inform behavioral coding of the videos (phase 1) and source code (phase 2). Analysis

¹Prior research has indicated that Stack Overflow is a dominant resource for students and programmers when seeking help using websites

³Approximately \$14 USD.

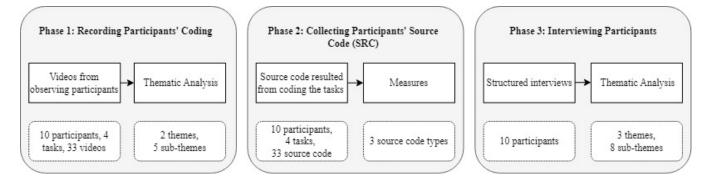


Fig. 1. Overview of research methodology: an online study in three sequential phases. A set of four video-captured programming tasks are followed by source code collection, and then an interview. The resulting qualitative data is thematically analysed.

TABLE I

STUDY TASKS, DIFFICULTY LEVELS, AND TOPICS. FIXED WIDTH TEXT DENOTES JAVA CLASSES, METHODS AND KEYWORDS. TOPICS MARKED WITH AN ASTERISK (*) WERE NOT EXPLICITLY TAUGHT IN THE FIRST YEAR JAVA COURSE, BUT WERE COVERED IN ADDITIONAL MATERIAL.

Task	Difficulty	Description	Topics assessed		
1	Easy	Easy Write a program that contains a two-dimensional array with the following values: 10, 20, 30, 40, 50, and 60. Declare and initialise a two-dimensional array with three rows and two columns. Then, using nested loops, print the array contents one by one in the same order.			
2	Easy	Write and implement a program which converts a sum of money into a different currency. The user will enter the amount of money to be converted and the exchange rate. The program will contain separate methods for getting the sum of money from the user, getting the exchange rate from the user, calculating the conversion, and displaying the result.	method definition, string input, string output		
3	Medium	Write a program to enter and confirm a suitable code name for a spy agent. Declare a String variable and then get the user to enter a suitable name as a codename. Check that the codename meets the following requirements:	String, .startsWith*, .endsWith*.		
		 The codename is greater than 6 characters in length. The codename starts with the word "Agent". The codename ends with an "X" character. 			
		If one of the conditions above was not met, print "INVALID CODENAME" and ask the user to re-enter a code name.			
4	Difficult	Using Java threading feature, create three threads where each has a unique name. Then, each thread should print the numbers from 1 to 100 in sequence order. For example, thread A will print numbers 1 to 100, thread B will print numbers 1 to 100, and thread C will print numbers 1 to 100.	threading*		

was done by first author. To ensure reliability of the coding, 30% of the data (i.e. three interview transcripts, ten videos, and source code from three participants) were additionally coded by third author, and any disagreements were resolved through a process of discussion and consensus, with nearperfect agreement (Cohen's k = 0.83, k = 0.87, and k = 0.83 for interviews, videos and source respectively; agreement 96%, 96% and 93%).

Interview transcripts (n = 10) were inductively coded using Braun and Clarke's six phases for reflexive thematic analysis [64] and NVivo 12.

Videos (screen recordings) were qualitatively analysed to observe [62, 65] and quantify participants engagement with websites when solving the study tasks. The same researcher again followed a reflexive thematic analysis approach [64] and linked the recorded videos to NVivo 12, given the large size of the video files.

In the first step of the reflexive thematic analysis, the researcher watched the videos multiple times for content familiarisation. Then, the coding phase started with watching and coding the related behaviours, using a deductive approach. In contrast to the interviews, this approach was analyst-driven, using findings from our phase 3 interviews as a framework to identify relevant behaviors [66]. The choice of such an approach ensured behavioural coding of the videos that focused on the study's research questions and objectives, and helped the researcher to know what to expect when coding the videos. However, any interesting and related behaviours outside this framework were also captured to ensure unbiased data. To facilitate the coding, a marker was placed at the start of each task in the videos. Coding the videos was an iterative process involving many rounds, despite requiring more time and effort.

Initial coding observed behaviours based on the initial framework. Th subsequent round sought to identify related behaviours not covered by the framework. The third round was to extract behaviours related to the source code for later analysis. After this round, two criteria were established to ensure that the captured behaviours were meaningful and

TABLE II

PARTICIPANTS' DEMOGRAPHIC AND EXPERTISE RESPONSES. EXPERIENCE IS A SELF-REPORTED VALUE FROM 1 TO 10, WHERE NOVICE=0, INTERMEDIATE=5, AND PROFESSIONAL=10. DURATION REFERS TO THE LENGTH OF TIME FOR WHICH THEY HAVE PROGRAMMED.

Participant	Gender	Age	Experience	Duration	Programming languages
P1	Male	20	5	Not available	Python, Java, C#, JavaScript, and R
P2	Male	20	7	One semester	Python, Java, C, C#
P3	Female	19	5	One year	Python and Java
P4	Female	19	5	5 years	4 programming languages
P5	Male	20	5	8 years	Python, Java, JavaScript, Typescript, C#, .NET, C, C++ and Swift.
P6	Female	20	5	6 years	Java, Python, C, C++, Web development
P7	Female	19	3	One year	Python
P8	Male	21	5	4 years	5 programming languages
P9	Male	20	5	3 years	Python, Java, C++ and Pascal
P10	Female	22	5	5 years	Java along with 9 programming languages

relevant. The criteria were that the behaviours had to be observed on the videos to constitute clear and reliable evidence and the behaviours should be measurable, in the sense that the videos provide enough information to support their serving as relevant evidence. The fourth round considered the mentioned criteria, checked the extracted behaviours and extracted any missing relevant behaviours. These multiple rounds ensured greater familiarity with the data and filtered behaviours down to relevant activities with multiple observed instances.

The next phase of the reflexive thematic analysis was grouping similar codes that form data patterns and share one overarching concept for the themes. For instance, codes that captured participants' behaviour toward online code adoption were grouped. The final set of themes was reviewed to ensure that no theme constituted a sub-theme to another theme or was not a theme in itself. Then, a thematic map was drawn to illustrate the final themes. Finally, a report on these behaviours was written.

A total of 33 videos (from a possible 40) were analysed. Five participants did not attempt Task 4, and so no videos were captured for these participant-task pairings. A further two missing videos (P10 Tasks 1 and P10 Task 2) were attributed to a failure of the Zoom recording facility.

Source code produced by participants was analysed for the 33 tasks for which video was captured. A mixture of quantitative and qualitative measures were established:

- 1) **Quantitative: Compilation/Execution** Was the researcher able to compile and run the source code either using an IDE or Command line in Windows?
- Quantitative: Correctness Does code execution produce the expected output (based on the specified tasks)?
- 3) **Quantitative: Online Clones** the number of lines copied and pasted from online sources (final non-commented source lines only) retrieved from reviewing the videos.
- Quantitative: Online Sources the URLs from which cloned code was sourced (retrieved from reviewing the videos).
- Qualitative: Clone Purpose the perceived motivation for including cloned lines (retrieved from reviewing the videos).

IV. RESULTS

A. The interview

Our thematic analysis revealed three themes: reasons for website use, experiences using websites, and study specifications and issues.

1) Theme 1: Usage of websites: Participants used websites for various purposes during their coding.

a) Websites as a reminder:

Nearly all participants reported that the websites, such as Stack Overflow, could serve as a reminder for information even if it were already known.

I do not try to remember the code if *I* know where it is exactly. [...] *I* am just reminding myself from the sources. (*P3*)

[...] it is often the same thing looking up just to check if you remember it correctly. (P6)

b) Copy online code:

All participants reported copying and pasting online code, even the previously encountered code or problems, due to the easyto-find online code.

[Q: What about copying code that you have previously copied during websites search?] Yeah, I would copy it again; some code I know where I can find it, so whenever I cannot remember it by heart, I know exactly where to find and then just copied it and then it works. (P8)

Most participants felt that the websites urged them to adopt available online content without checking, where the ease of obtaining online code gave a sense of no need to understand the code.

[...] I went ahead and copied the first things I saw [...] I think this is very common from write code pull up a page get something from the internet and continue coding. (P8)

c) Searching for information:

Participants described the procedures they took when searching the website for programming material. At the start, they get familiarised with the requirements to help determine the following step. I think my approach would usually be the same, read though the questions a few times and give it a go and see where I feel it does struggling and then start seeing if there anyone else done it in a smart way or whatever. (P9)

The following step is searching using the Google search engine without predetermining preference, as mentioned by most participants, and structuring the search query in a more appealing way related to the requested tasks.

I did not use a particular website, just try to figure most concise way to word my question and just see what comes up. (P9)

2) *Theme 2: Websites experience:* This theme tackles programmers' websites' preferences and potential concerns.

a) Websites choices:

Half of the participants reported that Tutorialwebsites provide clear, simple, understandable, self-sufficient, and easy to locate examples that offset the need to read the corresponding contents.

The one I usually chose is GeeksforGeeksor W3school. These two because it explains the best what I need to find, and the answers are on the beginning, so I do not need to scroll and read through everything. (P10)

More than half of the participants mentioned using of Stack Overflow because it provides reliable and genuine examples aiding problem-solving.

[...] I use Stack Overflow for for this one specific problem I was having because those questions are more specific. (P7)

The usage of the Stack Overflow is approached with care, as P5 noted:

And there is Stack Overflow, but you need take that in with some caution sometime. (P5)

b) Issues with the websites:

Many participants reported issues when using the websites. Some online answers were functional, but they were not necessarily great.

[Q: When searching the websites, were you confident that you got the right answer?]

Getting answers that works, but it is not always the best answers I would say. (P4)

Online answers additionally contributed to poor outcomes unsuitable for participants' intentions.

[Q: Did you find the websites easy to use, helpful, and correct?]

One give me a misleading data, so I would say no. (P8)

Thus, participants reported the possibility of facing problematic code or incomplete code that misses important information.

Sometimes the code on Stack Overflow can be a bit outdated, new version of framework or languages. Also, the users select an answer as the best answers that probably should not be, [...] like there are other answers better but not chosen by the user [...] who answer but it did not show up in the top. (P5)

The things it annoys me is website not showing the entire piece of code, so the thing that missing is something outside of the immediate bit of code they are showing. Like import statements, if the import statement is wrong and I cannot work out what it is, they very rarely show that I guess. (P4)

Participants were uncertain about their ability to integrate online code due to the associated problems.

Some problems are sometimes you are not working with your own code, so you are do not know everything about it, you do not know how the code interact with the code you find online. (P1)

Another impact was coding with unfamiliar programming aspects, where the websites did not help resolve such uncertainty.

[...] for the threading, I am not too familiar with threading, so I am not sure if it is what I wanted. (P8)

3) Theme 3: Experiment's specifications and issues.: This theme addresses participants' thoughts and concerns regarding aspects of the experiment.

a) Video recording:

More than half of the participants stated that their behaviours during the experiment followed their normal programming behaviours.

[Q: To what extends does the behaviours that you used today reflect the behaviours that you would normally use?]

I think pretty accurately. (P4)

Nevertheless, some behaviours were either not captured or did not reflect the programmers' normal behaviours. Two participants expressed that recording could conceal some behaviour or introduce unwanted factors to their programming activities.

[...] I would probably open up my notes and some written notes which obviously that I cannot show on the screen. (P2)

[Q: To what extends does the behaviours that you used today reflect the behaviours that you would normally use?]

It sorts of similar but in smaller scale. Usually I have got two monitors set up. (P5)

b) Time constraints:

Half of the participants felt that time constraints affected their performance in the experiment.

So today I try do it relatively fast because of the time thing. Normally I will take it a bit slower and maybe read more things. (P8)

The other half of the participants indicated no stress from the restricted time, and using some approaches would assist in regulating the time.

What I do when I started problems, I know it is time constrain I sort try to get the first few really quick or the one I spot easier, so I try manage the time better, and I know I have done it so it does not much so time constrain does not stress me. (P5)

c) Task Difficulty:

Participants reported that the tasks were not difficult but required more searching.

The tasks was not challenging. (P5)

However, four participants thought the fourth task could be challenging because they had no previous information, which may lead to not approaching the task.

I have not got the time to read it [fourth task], but I am not familiar with threading, so that why I left it. (P3)

Two participants thought the problems were not from the task but from forgetting the information and time.

My Java was a bit rusty, slight, I did not remember a lot of things how to do in Java in particular. But no, I think if I have a bit more time I will finish them all. (P2)

B. Behavioural coding

Participants used both Web-based and non Web-based resources to search. All participants used websites at various stages. Most participants used Tutorial websites to retrieve syntax, including GeeksforGeeks, W3school, JavaTpoint, "Java671", BeginnerBook and TutorialPoint. The choice of Tutorial websites changed based on the tasks. Other than Tutorial websites, Stack Overflow was used for resolving errors, and blogs were used to aid for understanding. In addition, participants consulted the requirements document for tasks' requirements, course-related materials, previously written code, and the IDE. Participants edited and compiled their code, going through a cycle of observing and fixing errors post-compilation.

1) Theme 1: Acquiring knowledge: Participants searched websites for syntax and to clarify understanding. Searches yielded useful knowledge, but also caused problems.

a) Looking for syntax: All participants searched websites for syntax either before or during coding. Before writing code, P6, P7, P8, and P10 in the fourth task and P3 and P8 in the first task searched for specific terms such as threading, "two-dimensional array" and the main method. The search for syntax while coding was noticed by nearly all participants who divided the tasks into meaningful searchable pieces and searched looking for syntax. Specifically, all participants in the first task, except P10, searched for "two-dimensional array" and basic syntax like for loop, main method and array. In a similar manner, all participants in the second task, except P2 and P10, searched regarding converting data types and getting user inputs, such as Scanner and Console. P4 and P9 searched for basic syntax, including Java function structure and .println, similar to the previous task. All participants in the third task searched syntax to retrieve String methods like .length, .startsWith, .endsWith, .charAt and .substring. P9 and P6 searched for basic syntax, include while loop while loop and "AND" symbol. In the fourth task, four participants (P5, P6, P8, P10) performed superficial searches, such as creating threads, assigning threads names and importing threads; P8 used the whole question text to search at the task's start.

b) Increase understanding: Participants sought programming information related to the task along with searching for syntax. P1 and P4 on the second task and P7 on the third task searched for syntax clarifications, such as the use of the .equals method for character type, the difference between Float and Double and the use of currency in Java. P7 and P10 also searched to gather information about the threading feature in the fourth task.

c) Experiencing problems during search: It can be observed that some online searches were unhelpful, causing additional time and effort. Eight participants struggled with online search across coding stages in all the tasks, and half of them returned to the previously visited Web pages. At the first task, P2 accessed various websites and searched for the nested "foreach" loop, resulting in more search time and attempts, then eventually changing the chosen method. In another instance, P2 searched for "two-dimensional array", and the outcomes did not help succeed in printing array elements accurately but motivated further searches that also did not help fix the issue. Similarly, P7 searched repeatedly for a "two-dimensional array" before writing it correctly. P9 searched for the main method and the .println statements without beneficial outcomes and resolved without searching. While coding the second task, P4 struggled the most as she searched five times for Float and Double, truncate Float, Decimal format and currency without valuable outcome: she sometimes returned to the previously searched results and chose another website. P6 and P7 searched for Scanner syntax, but their searches were not complete and caused further searches, and P4 and P9 conducted fruitless searches when converting data types from String to Float.

Online searching issues continued in the third task. Five participants faced issues related to String. P2 was affected the most as he searched for the getchar method in Java but adopted String declaring instead, then continued searching for the equivalent of getchar from C++ in Java and accessed three websites without reaching an answer. The previously adopted String declaring resulted in issues when compiling, causing two further search attempts, which was finally resolved by adopting a new code from websites; P10 shared a similar struggle while searching for the getchar method. In addition, search instances conducted by P3, P9 and P10 caused further search attempts, such as searching for String .length methods, split String and .substring. P8 searched for unnecessary syntax like "regex" and Matcher. Lastly, three participants (P7, P8, P10) in the fourth task searched for how to start one thread after another and count threads, then faced unproductive content, causing them to reformulate their query and repeat the search.

2) Theme 2: Utilising knowledge to write the code: Through seeking online knowledge, participants utilised the knowledge to develop their code. The following sub-themes will list participants' observed strategies when reusing online code.

a) Exploiting search results to copy code: All the participants copied online code snippets using two ways: a clipboard as a normal way and a visual way by looking at online code while writing it. There also appeared to be a further copy instance where participants examined particular code snippets from the websites and then wrote it in their code afterwards, and this copy instance will be labelled as a mental way. These three copy instances were conducted throughout the tasks with variance. Participants reused online code following the tasks' requirements. Seven participants in the first task, except P5, P6 and P10, copied "two-dimensional array". Similarly, all participants in the second task, except P10, copied syntax, like declaring and importing Scanner and converting syntax such as String to Float or Integer or the other way around. In the third task, all participants, except P5 and P10, copied .startsWith, .length, .endsWith, .charAt, .substring, Matcher and Scanner. At last, all five participants copied online code, including a class header, printing outputs and declaring the variables. Participants within all the tasks copied basic syntax from online, such as main method, for loop and .println statements.

b) Implementing complicated approaches: Participants followed suggestions imposed by either websites or their code practices causing additional coding time and effort. Videos observed such approaches that did not necessarily appear in participants' source code. Five participants (P2, P3, P4, P5, P9) in the first task followed online complex suggestions. In particular, P2 copied an online code that printed the array's contents using the toString method, which caused printing memory places, but not the array contents. Three participants (P3, P4, P5) used online suggestions to manually assign values to the array without using a loop, and P5 placed the array contents using three variables, each holding two array elements. P2 created four loops instead of two based on the online suggestions. A similar observation is valid for P1 but not from the online suggestions. In the second task, four participants (P3, P6, P8, P9) copied a user entry that used a String data type from online, then converted it to Integer data type. P5 and P1 followed the same path without online suggestions. In the third task, six participants (P2, P3, P4, P5, P8, P10) followed their code practices. P2 and P3 faced issues declaring multiple String variables and P4 and P10 made multiple unnecessary if statements that could be eliminated. P8 chose "regex" and Matcher, which resulted in several searches, debugging and more time. As most of the code was copied online in the fourth task, the online suggestions were only problematic for P7, who used three Run () methods with different names and loops, causing more searches to write them correctly.

C. Source code

Table III shows that nearly all participant-provided source code files compiled and executed successfully (28/33 files,

85%), and just over half (19/33, 58%) were considered to be correct (i.e. they met the requirements described in the task). Across the four tasks, participants produced at least two executables (mean: 2.80, median 2.50) and one correct source file (mean: 1.88, median 2.00). Progressively fewer source code files were correct as the tasks progressed (max: 9, min: 2).

All but one of the supplied source files (P5 Task 3) contained cloned code, with each participant including an average of 2.67 (mean, P1) to 8.50 (mean, P6) cloned lines per file (medians ranged from 1.5, P5, to 6.0, P4 & P10).

1) Correct: There were instances of unnecessary syntax on the first and fourth tasks increasing the complexity of the correct source code. In the first task, P1 and P2 in the first task used four loop statements instead of two to solve the "*twodimensional array*" where P2 wrote such code based on online suggestions, P5 copied online code and identified the "*twodimensional array*" using three array locations, and P3 printed the locations of the array along with the contents. In the fourth task, P7 followed the online suggestions and included multiple Run() methods for each thread, for loop, and .println statements.

Each of the correct source code were linked with video recordings to understand the strategies participants used to produce correct code. Regarding searching strategies, syntax searches were apparent throughout coding sessions for all participants, where they located items related to the task. Other than syntax searching, few searching occasions were attributed to clarifications. In addition, the online search resulted in multiple complicated issues faced by more than half of the participants who produced correct source code, which caused non-beneficial results and motivated further search attempts. Furthermore, all participants referenced the requirements document to check the requirements, and exhibited medium referencing in the first task, low in the second task, and high in the third task.

In terms of copying online code strategies, nearly all participants, who produced correct source code, copied online code in varied ways. On the contrary, copying from non Webbased resources is a rare strategy done by one participant. In addition, participants in twelve correct code instances ran into complex issues, half of them from their choice and the other half from the online suggestions.

2) Non-executable: Half of the third task participants (P2, P3, P4, P5, P9) (50%) failed to produce a functional compiled code. By analysing each source code within non-executable type, multiple reasons caused the code to be non-executable. Participants thought their code carried enough information while the code was incomplete, contained incorrect elements, or missed critical elements. In particular, P2 missed System.in that caused incorrect Scanner, used return() in the method while the method is void, used variable before declaring it, and wrote else if statement without including a condition. Similarly, P3 used else without a condition and missed the Scanner import, and P2 and P3 copied from online incomplete Scanner syntax and

TABLE III Results of Source Code Analysis.

	Not Provided	Non-Executable	Incorrect	Correct	Online Clones
Task 1	1: P10	0	0	9: P1-P9	9/9 files: 1–5 lines/file
Task 2	1: P10	0	4: P1, P3, P6, P8	5: P2, P4, P5, P7, P9	\bar{x} : 2.78, \tilde{x} : 3.0 9/9 files: 2–7 lines/file \bar{x} : 4.67, \tilde{x} : 5.0
Task 3	0	5: P2-P5, P9	2: P1, P7	3: P6, P8, P10	9/10 files: 2-6 lines/file
Task 4	5: P1-P4, P9	0	3: P5, P6, P10	2: P7 , P8	\bar{x} : 3.80 (4.22), \tilde{x} : 4.0 (4.0) 5/5 files: 6–24 lines/file \bar{x} : 12.00, \tilde{x} : 10.0

Note: In the First Four Columns, the Overall Number of Source Files in Each Category Is Followed By the List of Participants Whose Source Fell Into Each Category. Non-Executable Indicates That the Source Either Failed to Compile or Did Not Run to Completion. Incorrect Indicates That the Code Compiled and Executed Successfully but Produced Output That Was Not Compliant With The Requirements. In the Final Column, the Number of Files and Lines Containing Cloned Source Are Given, Together With the Mean (\bar{X}) and Median (\tilde{X}) Number of Cloned Lines Per File (Values in Brackets For Task 3 Indicate Averages for Files Containing Cloned Code).

encountered difficulty when adopting the code. In addition, P4 wrote four non-executable if statements, along with an incomplete .println statement. At last, the P5 and P9 source code contained incomplete main method and missed a semicolon.

The strategies that lead to non-executable code were explored for a more in-depth understanding. Participants excessively searched for syntax during coding, except for P5, and other searches were for learning. Searching produce issues as P2 conducted a repeating search with no successful output, and P3 and P9 conducted unnecessary searches. Most participants referred to the requirements document moderately, except P5 and P9. In the code strategies, online code was copied by all participants following mainly the visual way, except P5. Most participants made choices based on their practices that complicated their coding and used non Web-based code.

3) Incorrect: Multiple reasons caused the source code to not comply with the specified requirements. In the second task, P1 and P6 did not address Float or Double user entries (caused by copying online code for P1) and P3 and P8 missed doing methods for each requirement. In the third task, the String conditions wrote by P1 code did not function because it accepts non-string entries without processing, and P7 missed the while loop for continuous user entry. In the fourth task, P5, P6, and P10 printed threads but not in sequence order, and all solved the task engaging online.

Participants in this source code type conducted some common behaviours. In syntax search, the online search was generally prevalent, where participants looked for tasks related to syntax. Facing complex issues were not high during searching activities. Nearly all the participants resorted to the requirements document with moderate to high access. For the code strategies, copying the code has normal observations where participants copy online code and faced some complex issues.

V. DISCUSSION

This section discusses the study results and summarises the findings for each research question.

A. RQ1: How do programmers use websites during programming?

We found evidence from observations that the predominant use of websites was for retrieving syntax. Participants in our experiment referred to various resources, including websites, the requirements document, course-related materials, previous code and the IDE; websites were used predominately to search for knowledge. Participants preferred referring to the Tutorial websites to seek syntax, consistent with the findings of [52] but in contrast with other studies that suggest programmers use Stack Overflow for coding [19]. They started their search by decomposing the tasks into searchable parts, similar to observations in [40].

Two interesting observations were made in relation to searching: it was common to search for Java basic syntax such as main method, .println statements and loops syntax, and previously taught syntax such as "two-dimensional array" and user entry methods. Interviews with participants showed they relied on websites to remind them of this basic information, which they may have been able to retrieve from memory if they had not had access to the websites. This tendency to search for basic syntax has also been seen in [5, 9]. Participants in our study preferred not to trust their memory of the syntax itself, but rather to rely on their ability to find it online, supporting the notion of using the websites as a reminder [2]. Participants also searched websites for, e.g., the equivalent of getchar from C++ in Java, suggesting that previous knowledge (especially knowledge of another programming language) plays a role in the search process. In some cases, participants searched continuously, without appearing to get relevant results. Failing to obtain relevant information in spite of repeated searchers has also been noted in [9, 19].

Participants copied code from websites and used it within their programs. Participants used code found online more in the fourth task than other tasks suggesting that the more difficult or unfamiliar the task, the greater the need to use online code. Using websites to help with unfamiliar tasks involves dealing with uncertainty about the information found, as expressed in the interviews. Participants were observed to copy online code, including basic and taught syntax, in three ways: using copy and paste functionality; observing it and retyping it; memorising it then retyping it. They reported in the interviews that the reason for using online code is the ease with which it can be located. It appears easier to search for basic syntax every time it is required than to commit it to memory.

B. RQ2: What are the effects of websites use on the resulting code?

Using the websites while coding helped participants to produce correct code that met requirements. Where participants produced non-executable code, this was not due to using websites per se, but rather poor programming practices. Nevertheless, there were many instances where participants did not exploit online content efficiently. Copied code was sometimes neither suitable for nor required by the task. Examples are the manual assignment of array values, not printing array contents, unsuitable data types for user entries, redundant code and unnecessary multiple Run () methods. Participants appeared to trust the code without giving it much scrutiny, at the expense of efficiency and effectiveness. It is not possible to know whether better code would have been written were the websites not available, but it is certainly the case that wholesale or unthinking inclusion of online code did not always result in satisfactory code. In the interviews participants reported that websites urged them to use code as presented, but we can see that this sometimes resulted in negative outcomes. The difficulty of reusing online code is also observed superficially in [10, 11]. The findings of this study suggest that while reusing online code can be effective, it can also cause complex problems that require time and effort to resolve. Programmers need to consider the associated time and effort while coding using the websites.

Issues we observed in the code included: increased complexity; extraneous unwanted or unexpected outputs; and bugs [57, 59]. Participants reported two additional issues in the interviews: outdated and incomplete problematic code [22, 54, 56]. A possible explanation for these issues is that Websites state the code is safe to use as is; this was also mentioned in the interviews. Thus, it is necessary to reflect on the online presented content and ensure its accuracy.

Other factors may have affected the accuracy of source code, including task difficulty, time constraints and previous experience. While participants had previously been taught how to achieve most of the tasks, difficulty appeared to be a factor – production of valid code reduced as task difficulty increased. However, participants reported in the interview that the tasks were not difficult to code, indicating they may have been unaware that code did not meet requirements.

C. Recommendations

The findings in this paper have applications for stakeholders across software engineering, including owners of the Websites, educators, researchers and tools builder. The following sections distill these findings into some concrete recommendations.

- 1) Recommendations for owners of the Websites:
- Owners of the websites should advise their content authors to consider the problematic code from the programmers' perspective and fully explain their online posted code.
- Owners of the websites should advise their content authors to consider that users with various experiences may consider their posted code.
- 2) Recommendations for educators:
- Educators should providing training in online information seeking, including how to search effectively, source selection, and appropriate expectations for online content.
- Educators should train students to engage in judicious code reuse, equipping them to make sound judgements about the suitability of code snippets. This includes supporting them in determining when (and which parts of) code snippets are relevant and recognising problematic code.
- 3) Recommendations for researchers:
- Researchers can further investigate the search and code reuse strategies and propagation of problematic code by collecting or analysing ready sets of code.
- 4) Recommendations for tools builder:
- Tools builder could exploit the findings by designing a tool that identify programmers' copy-and-paste activities when using websites and suggests follow-on activities such as the review of copied code for understanding, fit with requirements, and quality control.

D. Limitation

Participants' source code contained relatively few lines, providing little room to analyse the impact of website use. The study's design introduced no baseline with which to compare coding with or without using the websites. Asking participants to code without websites would not have been meaningful, and participants may have been reluctant to take part in a study designed that way. Also, repeating the study with the same participants would introduce previous exposure to the tasks.

In addition, to minimise threats to construct validity, a pilot study was used to validate and refine the tasks and the study's phases. One threat to construct validity could have been a concern about using appropriate tasks to reflect upon the coding activities. Task design ensures participant familiarity by using previous materials, and ensures online content support solving the tasks. Other threat may have emerged as a property of recruiting student participants from the University of Manchester. Whilst it was clearly indicated to participants that their data would be treated anonymously, to prevent impact on their study or outcomes, students may still have been reluctant to divulge behaviours that they thought academe would perceive negatively. Students at UK universities are regularly advised against activities that might constitute plagiarism, such as copying and pasting from external sources, and this therefore may have led students to minimise disclosure of these behaviours during their coding sessions and interviews.

This study does not set out to examine causal relationships, and the internal validity is of limited concern. However, potential influence by external factors could have included experiment time, settings and researcher availability influencing their coding. The study uses multiple data sources to ensure triangulation, including observations, source code and interviews. While the findings of this experiment resulted from solving programming tasks, the observed behaviours may vary based on the tasks. Time also play an important role in solving the tasks. In addition, steps were taken to involve multiple members of the research team at every step. An interrater reliability method was further conducted to increase the reliability of the findings.

VI. CONCLUSION

We conducted an online experiment to explore programmers' activities during coding tasks using websites, analysing the resulting source to uncover possible consequences on the code. Recordings and source code for ten programmers solving four programming tasks were collected, and participants were interviewed. Recordings and interviews were thematically analysed, and source code analysed through a combination of quantitative and qualitative measures.

The observations have revealed that the vast majority of searches on websites were for syntax and involved tutorial websites. Syntax search comprised breaking down the task into searchable chunks and was usually for syntax that was basic, and had been previously taught. Participants copied code in three ways: using copy and paste functionality; observing it and retyping it; memorising it then retyping it. The copied syntax was not always appropriate or necessary for solving the task.

Participants produced source code in three categories: correct, which was working according to the requirements; nonexecutable; and incorrect, which was compiling/running but non-compliant with the requirements. Participants used various strategies during their coding using the websites, and these strategies were linked with participants' source code to investigate their outputs for any implications. Although coding with websites and encountering complex issues that increased task completion time and effort helped participants produce correct code, using websites impacted the resulting code, producing either incorrect or non-executable code. Thus, using websites during coding produced incorrect code.

Programmers need to consider the time and effort it takes to use websites, reflect carefully on their requirements to help filter online content, and not presume that online content is accurate. Future work should explore these findings with other samples, for example, professional programmers.

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