Students Perceptions of Authentic Learning for Learning Information Flow Analysis

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***Abstract*—This research-to-practice paper reports students' perceptions on using a teaching framework called authentic learning to learn about information flow analysis. Using information flow analysis, practitioners find the flow of data across one or multiple programs. Information flow analysis is helpful for multiple software engineering activities, such as detecting software bugs and developing software fuzzing techniques. Despite being helpful in practice, learning about information flow analysis remains an impediment for students, which in turn prevents them from reaping the benefits of using information flow analysis. Therefore, an application of a teaching framework can aid students in learning about information flow analysis. To that end, we systematically investigate if authentic learning—a teaching framework that emphasizes on providing hands on experience for a practically relevant topic—is helpful for students to learn about information flow analysis. Upon conducting the exercise, students are asked to participate in a survey where they report perceptions about the conducted exercise. We analyze data from 170 students who were introduced to information flow analysis through an authentic learning-based exercise.**

From our analysis, we observe: (i) majority of the students to have little to no knowledge about information flow analysis prior to conducting the authentic learning-based exercise; (ii) 74.1% of the 170 students find the authentic learning-based exercise helpful to learn about information flow analysis; and (iii) student perceptions to vary for the three components of the authentic learning-based exercise. We conclude our paper by describing the implications of our findings for instructors and researchers. For example, instructors should consider the education level of students while designing activities for individual authentic learning components to educate students on information flow analysis. Furthermore, researchers can devise strategies on how instructors can allocate their efforts for each authentic learning component through empirical studies. These studies may investigate the correlation between reported helpfulness and socio-technical factors, such as education level of students.

***Index Terms*—authentic learning, exercise, experience report, information flow analysis, perception, static analysis**

I. Introduction

Information flow analysis is the technique of tracking the flow of data or execution across one or multiple computer programs [1], [7]. Information flow analysis enables practitioners to understand and utilize how value of a program entity, e.g. a variable, changes across a program. Information flow analysis has helped practitioners to detect bugs in software source code [4], [24], [27], develop automated software fuzzing techniques [6], and develop software applications that monitor privacy violations in smartphones [11]. According to Mathis et al. [22], information flow analysis is"*central in assessing the security of applications*". The helpfulness of information flow analysis has motivated instructors to incorporate education materials related to information flow analysis in courses related to software engineering [25].

Despite being used in course curriculum, dissemination of information flow analysis amongst students poses a challenge. In recent work, Rahman et al. [25] found students to underperform in exercises related to information flow analysis. While describing their experiences of conducting exercises related to software engineering, Rahman et al. [25] found students to "*to perform the worst*" for the exercise related to information flow analysis. They [25] advocated for integration of teaching frameworks to help students learn about information flow analysis.

One approach to educate students on information flow analysis can be development of exercises using authentic learning. Authentic learning is a teaching framework that emphasizes on providing students hands-on experience on a topic that has practical relevance [19], such as information flow analysis. Collection and analysis of students' perceptions is pivotal in this regard, as prior research [9], [31], [32] shows teaching frameworks can improve by accounting for students' perceptions. Struyven et al. [32] mentioned that collection and analysis of student perceptions is often neglected, and "*cannot be neglected if full understanding of student learning is the purpose of our educational research and practices*". Through an empirical study we can characterize student perceptions of authentic learning components, which in turn can yield recommendations for instructors on how to adopt authentic learning for teaching information flow analysis. While prior research has investigated students' perceptions for bot-based teaching frameworks [33], blended learning [8], and cybersecurity [25], [26], similar endeavors remain under-explored for teaching students about information flow analysis.

Accordingly, we answer the following research questions:

- ***RQ1*: What are the student perceptions of an authentic learning-based exercise to learn about information flow analysis?**

- ***RQ2*: What are the student perceptions of individual components of an authentic learning-based exercise to learn about information flow analysis?**

In our paper, we describe our experiences in conducting an authentic learning-based exercise for students to learn about information flow analysis. We quantify the perceptions by analyzing data from 170 students enrolled at Auburn University (AU). We apply ordered logistic regression [15] to quantify the correlation between students' outcomes and students' perceptions. Next, we analyze students' perceptions of the components used for the authentic learning-based exercise. Dataset, source code, and instruments to conduct the exercise is available online [5]. We abide by all guidelines provided by the Internal Review Board (IRB) at AU while conducting this research study.

Contribution: We list our contributions as follows:

- An evaluation of perceived helpfulness of authentic learning to learn about information flow analysis; and
- A publicly available replication package that contains the dataset, source code, and survey questionnaire necessary for conducting the empirical study.

II. Related Work

Our paper is related with prior publications that have investigated teaching frameworks to educate students on topics related to software quality assurance. Valle et al. [13] found game-based learning to be helpful for learning software testing. Aniche et al. [2] investigated how the 'pragmatic' technique can be helpful for instructors to teach software testing by analyzing feedback reports and survey responses. Richardson et al. [30] applied and quantified the effectiveness of problem-based learning to educate students on software quality assurance. Jacchery and Letizia found industry interactions to be helpful in educating students on software quality assurance.

Our paper is also related to prior research that have used authentic learning. For example, Qian et al. [23] used authentic learning to develop web security education modules. Lo et al. [18] used authentic learning to develop module related to mobile application development. Hermann and Popyack [14] used authentic learning to educate non-CS students introductory level programming concepts. Rahman et al. in separate publications found authentic learning to be useful for teaching concepts related to infrastructure as code [28] and white-box testing [29].

We observe a plethora research that have studied frameworks to effectively disseminate software quality assurance in the classroom but a lack of research that focuses on teaching frameworks to foster the teaching process of information flow analysis. We address this research gap by conducting an empirical study where we quantify students' perceptions on authentic learning for learning information flow analysis.

III. Methodology

A. Background Information on Authentic Learning

We provide necessary background information in this section.

1) Background on Authentic Learning: Authentic learning is a teaching framework that emphasizes on exposing students to real-world problem-based activities [19]. Curriculum modules developed using authentic learning practices include certain characteristics [21]: (i) focusing on hands-on exercises that have relevance to the real-world, (ii) allowing for students to have a diverse set of perspectives for the same exercise, and (iii) facilitating availability of resources to solve the exercises. An authentic learning-based exercise consists of three components: *first, as part of pre-lab content dissemination*, prior to the conducting the exercise necessary background is provided to students. *Second, as part of in-class experience*, students are provided hands-on experiences within a classroom setting, so that students gain necessary hands-on experience by working on a problem that has real-world relevance. *Finally, as part of the post-class activity*, after the in-class experience is complete, students are asked to solve a problem that is a variant of the in-class problem.

Figure 1 summarizes the main components of authentic learning. Each of the three components of an authentic learning-based exercise is mapped to a pedagogical step. The pre-lab content component is mapped to 'Initiate', the in-class experience component is mapped with 'Engage', and the post-class component is mapped to 'Apply'. The 'initiate' step is expected to initiate discussion amongst students about information flow analysis. The 'engage' step is expected to trigger enthusiasm and engage students about the topic. The 'apply' step is expected to get students apply their obtained knowledge a relevant problem. As shown in Figure 1, as the steps change, the students are expected to obtain a specific mindset. The transition from pre-lab content to in-class experience is expected the students to be at an 'engagement' mindset, whereas, the transition from post-class activity will put the students in an 'extension' mindset, where the students are expected to use their knowledge from the authentic learning-based exercise to extend and enhance the topic of interest.

2) Background of the Instructor: The authentic learning-based exercise was deployed in three iterations of a course titled 'Software Quality Assurance' at AU in Fall 2022, Spring 2023, and Fall 2023. 'Software Quality Assurance' is a cross-listed course, i.e., a course that includes students enrolled in the Bachelors of Science and Masters of Science program. We refer to the Bachelors and Masters of Science students respectively, as B.Sc. and M.Sc. students throughout the paper.

The instructor of the course is an assistant professor with five years of teaching experience in an academic setting. The instructor's research interest is in the area of software quality assurance. The instructor also comes with seven years of professional industry experience. Prior to conducting the exercise the instructor provided these background information.

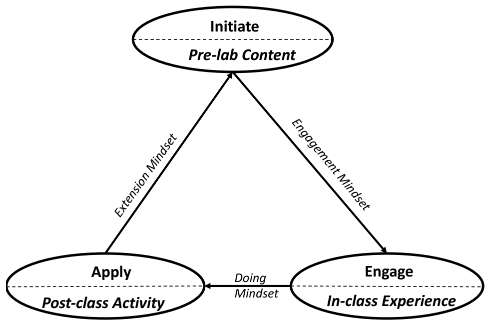


Fig. 1: An overview of the pedagogical steps of an authentic learning-based exercise.

3) Background on Exercise Related to Information Flow Analysis: We apply authentic learning [19] to construct an exercise for students to learn about information flow analysis. Graduate students, as well as undergraduate students in their senior or junior year with a CGPA of $>= 3.4$ can enroll in this course. The exercise of interest focuses on information flow analysis, which consists of three activities:

1) *Pre-lab content dissemination*: As part of this activity, the instructor provided detailed background on information flow analysis and parse trees. The instructor also described their experiences in using information flow analysis in an industry and academic setting. The instructor explained how parse trees can be leveraged to extract necessary information about a computer program. Next, the instructor used the Python program presented in Listing 1 to showcase the flow of variable `v1`, and how it is used by variable `res`.
2) *In-class experience*: As part of this activity, the instructor conducted a live demonstration on how to develop a Python program so that the variable `v1` can be tracked within the function `simpleCalculator` automatically. As part of the live demonstration, using the 'ast' library [3], the instructor wrote a function that extracts variables, and the assigned values to those variables. Upon execution the program printed out `v1->res` showcasing that `v1` is used by `res`.
3) *Post-class activity*: As part of this activity, the students are asked to develop a program that prints `100->val1->v1->res` for the program listed in Listing 2. The students were allowed to use the computer program developed as part of the in-class activity. Upon completion of the assignment, students are asked to submit their code. The students are also asked to complete the survey. We have described the construction and deployment process of the survey in Section III-B.

Once the deadline is over the instructor grades the exercises. Each student is assigned any of the following grades: 'A', 'B', 'C', 'D', and 'F', where 'A' is the highest. The instructor

```
def simpleMethod(v1):
    res = v1 * 10
    return res
```

Listing 1: Python code snippet used for pre-lab content dissemination.

```
def simpleCalculator(v1, v2, operation):
    res = 0
    if operation=='+':
        res = v1 + v2
    elif operation=='-':
        res = v1 - v2
    elif operation=='*':
        res = v1 * v2
    elif operation=='/':
        res = v1 / v2
    elif operation=='%':
        res = v1 % v2
    return res


if __name__=='__main__':
    val1, val2, op = 100, 1, '+'
    data = simpleCalculator(val1, val2, op)
    print('Operation:{}\nResult:{}'.format(
     ↪  op, data  ) )
```

Listing 2: Python code snippet used for the post-class activity.

assigns 'A', 'B', 'C', 'D', and 'F' respectively, for completion of 85-100%, 61-84%, 41-60%, 15-40%, and less than 15% of the assigned tasks.

B. Survey Construction and Deployment

We use an online survey to collect feedback from students on the helpfulness of the authentic learning-based exercise. We describe the construction and deployment of the survey respectively, in Sections III-B1 and III-B2.

1) Survey Construction: For our survey, we ask three categories of questions that are related with: (i) students' background, (ii) students' experience on authentic learning, (iii) and students' perceptions of the authentic learning components used for the exercise.

Questions related to the students' background: We ask three questions that are related to the students' background: (i) "What is your education level?"; (ii) "How would you rate your experience related to software quality assurance activities, such as debugging and testing?"; and (iii) "How would you rate your experience with information flow analysis prior to the workshop?". For the first question, we provide the following options: 'Graduate - M.Sc.', 'B.Sc. - Senior', and 'B.Sc. - Junior'. We provide these options as only junior or senior year undergraduate students and M.Sc. graduate students are allowed to enroll in this course. For the second question we use a five-item Likert scale question following Kitchenham's recommendations [17]: 'Expert', 'Somewhat expert', 'Knowledgeable', 'Little knowledge', and 'No knowledge'.

Questions related with students' experiences on authentic learning: We ask "Did the authentic learning-based workshop help you to learn about information analysis?", which is a five-item Likert scale question with the following items: 'Very helpful', 'Helpful', 'Somewhat helpful', 'Little helpful', and 'Not at all helpful'.

Questions related with students' perceptions of authentic learning components: We also ask students about their perceptions of the three authentic learning components: pre-lab content dissemination, in-class experience, and post-class activity. We assume that by analyzing students' responses to these questions, we can quantify whether or not each component of the authentic learning-based experience is helpful to learn about information flow analysis. We ask the following questions that correspond to each of the three components: (i) "How helpful was the pre-lab content dissemination to learn about information flow analysis?", (ii) "How helpful was the in-class experience to learn about information flow analysis?", and (iii) "How helpful was the post-class activity to learn about information flow analysis?". Following Kitchenham's recommendations [17], for all of these questions we use a five-item Likert scale question with the following items: 'Very helpful', 'Helpful', 'Somewhat helpful', 'Little helpful', and 'Not at all helpful'.

2) Survey Deployment: Prior to deployment of the survey we seek approval from the IRB authority at AU. As per IRB guidelines, we do not collect personal information of students. We use a unique identifier with Qualtrics so that student responses remain anonymous. We also agree to not release the individual grades of students.

Students of the course pursued the survey after completing the exercise. Instructor of the course deployed the survey using the online Qualtrics platform [1]. Prior to participation each survey participant was asked for consent.

C. Analysis

We use survey responses to answer our research questions:

1) RQ1: What are the student perceptions of an authentic learning-based exercise to learn about information flow analysis?: We answer RQ1 by first reporting the students' responses for the question: "*Did the authentic learning-based workshop help you to learn about information flow analysis?*" Next, we use quadratic ordinal logistic regression (OLR) [20] to quantify if authentic learning is correlated with students' outcomes for the exercise. We use OLR because it quantifies correlations between dependent and independent variables, where dependent and independent variables are ordinal factor variables [15]. Using OLR, we construct a model where the dependent variable is an ordinal variable that corresponds to students' obtained grades for the exercise, i.e., 'A', 'B', 'C', 'D', and 'F'.

In our model, the independent variables are:

[1] https://qualtrics.com/

1) Helpfulness of authentic learning reported by the students ('Authentic Learning'): For helpfulness of authentic learning, the answers are recorded using a five-item Likert-scale: 'Extremely helpful', 'Helpful', 'Moderately helpful', 'Little helpful' and 'Not helpful at all'.
2) Students' level of education ('Education Level'): Students' education level is a binary variable with two values: 'BSC' and 'MSC', which respectively, corresponds to the undergraduate and graduate level.
3) Students' experience in information flow analysis ('Experience in IFA'): In the case of students' experience in information flow analysis, the Likert items are: 'Expert', 'Somewhat expert', 'Knowledgeable', 'Little knowledge'. and 'No knowledge'.
4) Students' experience in software quality assurance ('Experience in SQA'): In the case of students' experience in software quality assurance, the Likert items are: 'Expert', 'Somewhat expert', 'Knowledgeable', 'Little knowledge'. and 'No knowledge'.

For the OLR model, we report: (i) p-value for each independent variable. We determine a variable to have a correlation with obtained grades if the p-value for that metric is < 0.05; (ii) coefficients and sum of square errors for each independent variable [16], [20]; and (iii) McFadden R2 [34] of the constructed OLR model.

2) RQ2: What are the student perceptions of individual components of an authentic learning-based exercise to learn about information flow analysis?: RQ2 focuses on analyzing students' perceptions of individual components of the authentic learning-based exercise. As part of our analysis, we report the percentage of students who have reported the helpfulness for each component using the five-item Likert scale: 'Very helpful', 'Helpful', 'Somewhat helpful', 'Little helpful', and 'Not at all helpful'.

IV. RESULTS

We collect responses from 170 students at AU who submitted code for the exercise and completed the survey. Of the 170 students, 33 are graduate students enrolled in M.Sc. in Computer Science. The remaining 137 students are senior year undergraduate students enrolled in B.Sc. in Computer Science. All of the enrolled B.Sc. students are in their final year of their degree.

We provide data related students' reported experience in information flow analysis and software quality assurance respectively, in Figures 2 and 3. We observe nuances with respect to students' reported experience for information flow analysis and software quality assurance. In the case of information flow analysis, we observe 70.8% of the B.Sc. students to have 'little' or 'no' knowledge about information flow analysis. For information flow analysis, we observe 51.6% of the M.Sc. students to have 'little' or 'no' knowledge about information flow analysis. In the case of software quality assurance, we observe 58.4% of the 137 B.Sc. students reported to have 'little' or 'no' knowledge. We observe 39.4% of the 33 M.Sc. students to have 'little' or 'no' knowledge about software quality assurance. We observe that students' reported software quality assurance experience is higher than that of information flow analysis. We also observe, the proportion of M.Sc. students to have more knowledge on information analysis and software quality assurance compared to that of B.Sc. students.

A. Answer to RQ1: What are the student perceptions of an authentic learning-based exercise to learn about information flow analysis?

We report the students' perceptions of the authentic learning-based exercise in Figure 4. From Figure 4a, we observe 71.5% of the B.Sc. students to find the exercise 'Helpful' or 'Very helpful', whereas, from Figure 4b we observe 84.9% of the M.Sc. students to find the exercise 'Helpful' or 'Very helpful'. Based on our analysis, we observe the authentic learning-based exercise to be helpful more for M.Sc. students even though their reported experience is higher than that of B.Sc. students. From Figure 4c we observe 74.1% of all 170 students to find the authentic learning-based exercise to be 'helpful' or 'very helpful' to learn about information flow analysis.

We report the students' obtained grades in Figure 5. According to Figure 5a, 93.5% of the B.Sc. students obtained the highest grade ('A'). As shown in Figure 5b, 97% of the M.Sc. students obtained the highest grade ('A'). Overall, from Figure 5c we observe 94.7% of the 170 students to obtain a grade of 'A'.

From Figure 4 we observe majority of the students to find the authentic learning-based exercise helpful to learn about information flow analysis. Also, from Figure 5 we observe majority of the students to obtain the highest possible grade suggesting a correlation between perceived helpfulness and learning outcomes as measured by grades.

With logistic regression, we further investigate if there is a quantitative relationship between perceptions of authentic learning and learning outcomes. The logistic regression results are available in Table I. The p-value is < 0.01, which confirms the correlation between perceived helpfulness for the authentic learning-based exercise and obtained outcomes. The McFadden R2 is 0.3. A McFadden R2 value between 0.2 and 0.4 is a good indication of well-fitted model [34]. The highlighted cells in green show which of the independent variables show correlation with obtained grades. We find perceptions related to authentic learning ('Authentic Learning') and knowledge in software quality assurance activities ('Experience in SQA') to correlate with obtained grades.

From Table I, we also observe experience in software quality assurance activities ('Experience in SQA') to show correlation with obtained outcomes, where the coefficient estimate is higher than that of perceived helpfulness of authentic learning ('Authentic Learning'). One possible explanation is that the students who reported to be knowledgeable about software quality assurance are also familiar with information flow analysis informally through software engineering activities, such as debugging and testing in other academic courses that are taught at AU. With activities, such as debugging and testing, practitioners read and comprehend source code, which in turn aids them in understanding the flow of data and control within source code programs [10], [12], [35]. Another possible explanation is related to students' professional experience related to information flow analysis that informally involved information flow analysis through full-time and part-time professional opportunities. Through these experiences students may have gained practical knowledge that enabled them to learn about information flow analysis.

TABLE I: Answer to RQ1: Authentic Learning and Its Correlation with Learning Information Flow Analysis (All)

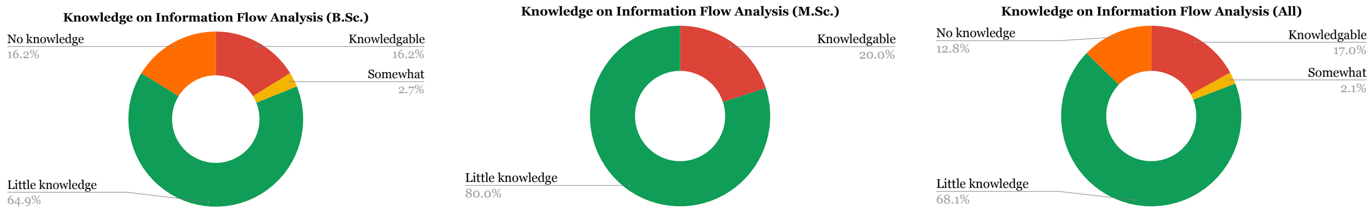
Independent Variable	Coeff. Estimate	Error	p-value
Authentic Learning	12.4	0.8	< 0.001
Experience in IFA	0.62	0.6	0.7
Education Level	-0.04	0.9	0.9
Experience in SQA	14.0	0.5	< 0.001

Students' statements also supports our quantitative evidence reported in Table I. For example, one student stated: "*Very useful workshop, didn't know what this [information flow analysis] was prior. Always nice to learn a new facet of software engineering. Definitely increased the extent of my knowledge within software engineering.*" Another student remarked: "*Never seen this concept before. Very interesting!*". In summary, we observe quantitative and qualitative evidence of an authentic learning-based exercise to be helpful for students to learn about information flow analysis. Our logistic regression-based results reported in Table I confirms the correlation between perceptions related to authentic learning and outcomes as measured by grades. Students' experience in software quality assurance activities is also correlated.

B. Answer to RQ2: What are the student perceptions of individual components of an authentic learning-based exercise to learn about information flow analysis?

The perceptions of the pre-lab, in-class, and post-class components of the exercise is respectively, shown in Figures 6, 7, and 8. We observe the perception-related trends for pre-lab, in-class, and post-class components of the exercise is similar to that of overall perceptions of the authentic learning-based exercise.

From Figure 6 we observe M.Sc. students to find the pre-lab component of the exercise more helpful than that of B.Sc. students. For example, 75.8% of the M.Sc. students found the exercise to be 'helpful' or 'very helpful', whereas, the number is 62.8% for B.Sc. students. Similar trends are observant for the in-class component of the exercise as well where the in-class component is perceived to be more helpful for M.Sc. students compared to that of B.Sc. students. According to Figure 7, of the 33 M.Sc. students, 72.8% perceive the in-class component to be 'helpful' or 'very helpful'. The



a b c

Fig. 2: Reported experience of students in information flow analysis.

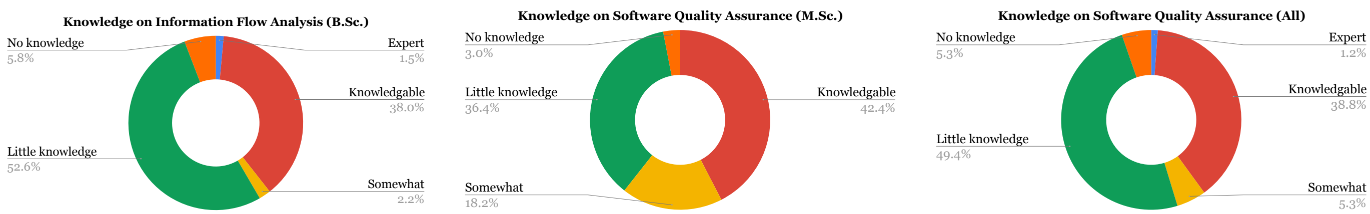


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Fig. 3: Reported experience of students in software quality assurance.

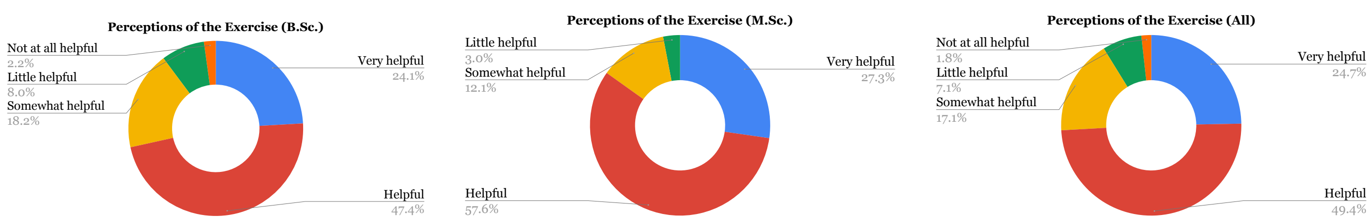

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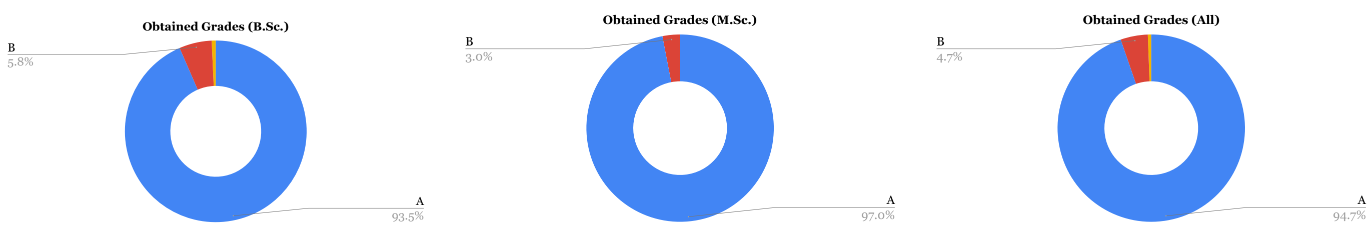
Fig. 4: Students' perceptions of the authentic learning-based exercise.



a b c

Fig. 5: Outcome from the authentic learning-based exercise as measured by grades.

percentage is lower for B.Sc. students: 70.1% of the 137 B.Sc. students find the in-class component to be 'helpful' or 'very helpful'. According to Figures 7a, 8a, and 6a across all three components, the in-class component of the exercise received the highest proportion of positive perceptions from B.Sc. students: 70.1% of the B.Sc. students found the in-class component of the exercise 'helpful' or 'very helpful', as shown in Figure 7a. On the contrary, the post-class component is perceived as most helpful by M.Sc. students, where 84.8% of the M.Sc. students found the post-class component of the exercise 'helpful' or 'very helpful'.

According to Figure 8, considering all 170 students the proportion of positive perceptions is highest for the post-class component of the exercise. As shown in Figure 8c, 71.7% of the students find the authentic learning-based exercise as 'helpful' or 'very helpful' to learn about information flow analysis, compared to 65.3% and 70.6% that we have respectively, observed for the in-class and pre-lab components in Figures 6c and 7c. The proportion of students who found the post-class component of the exercise 'helpful' or 'very helpful' is 68.6% and 84.8% respectively, for B.Sc. and M.Sc. students.

In summary, we observe student perceptions to vary for the three components of the authentic learning-based exercise. B.Sc. students tend to perceive the in-class component more positively compared to that of the other two components. The post-class component enjoys more positive perception than the other two components in the case of M.Sc. students.

V. Discussion

We discuss the findings of our paper as follows:

A. Usefulness of Authentic Learning

Obtained grades from Figure 5 showcases majority of the students to perform well for the exercise. Furthermore, according to Figure 4 after completing the exercise 74.1% of 170 students found authentic learning 'very helpful' or 'helpful' in learning information flow analysis. All of this shows how an authentic learning-based exercise can be helpful for students to learn information flow analysis. Such conclusions can be further substantiated by the findings reported in Table I, where we observe perceived helpfulness to have a significant correlation with obtained outcomes.

> ***Implication#1**: Authentic learning-based exercises are helpful for students to learn about information flow analysis.*

B. Implications for Instructors

While results reported in Section IV-A demonstrate the helpfulness of authentic learning, students have nuanced perspectives of the authentic learning-based exercise. For example, as discussed in Section IV-A, we observe M.Sc. students to perceive authentic learning to be more helpful compared to that of B.Sc. students. We also observe M.Sc. students to find post-class activity to be more helpful compared to that of B.Sc. students. Majority of the B.Sc. students found in-class experience to the most helpful amongst the three authentic learning components. All of this evidence showcases differences in perceptions when it comes to the helpfulness of authentic learning components.

The differences in component-related perceptions between B.Sc. and M.Sc. students have implications for instructors. In the case of an undergraduate-only course, the instructor should allocate substantial amount of time on in-class activity for an authentic learning-based exercise. The instructor can further consider aligning the exercises demonstrated as part of the in-class experience and post-class activity. In the case of a graduate-only course, instructors can consider allocating more time on the post-class activity, as according to Figure 8b, M.Sc. students tend to appreciate post-class activity more.

> ***Implication#2**: Instructors should consider the education level of students while designing activities for individual authentic learning components to educate students on information flow analysis.*

C. Implications for Researchers

Results reported in Section IV-B show another perspective of students perceptions about the authentic learning-based exercise for learning information flow analysis. We observe not all components of authentic learning to be equally perceived as helpful for students. B.Sc. students found in-class activity to be more helpful compared to that of M.Sc. students. Unlike, B.Sc. students, M.Sc. students found post-class activity to be the most helpful amongst the three components of authentic learning. One possible explanation is that education level can have an implicit correlation with perceived helpfulness of each authentic learning component. Another possible explanation is the exercise of post-class activity is more challenging than the in-class activity for which M.Sc. students navigated with more success compared to that of B.Sc. students. As part of future research, researchers can support or refute these explanations with empirical studies.

> ***Implication#3**: Researchers can devise strategies on how instructors can allocate their efforts for each authentic learning component through empirical studies. These studies may investigate the correlation between reported helpfulness and socio-technical factors, such as education level of students.*

VI. Threats to Validity

We discuss the limitations of our paper as follows:

- **Conclusion Validity**: Our findings are limited to the survey responses we collect from the course. The count of survey respondents is 170, which might be limiting. Our derived analysis for RQ2 is based on student perceptions of authentic learning components, which is prone to bias. We mitigate this limitation by using a five-item Likert-item

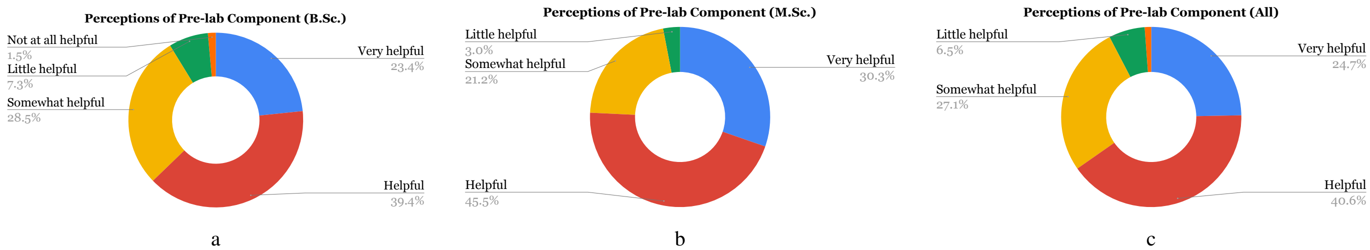


Fig. 6: Students' perceptions of the pre-lab component of the authentic learning-based exercise.

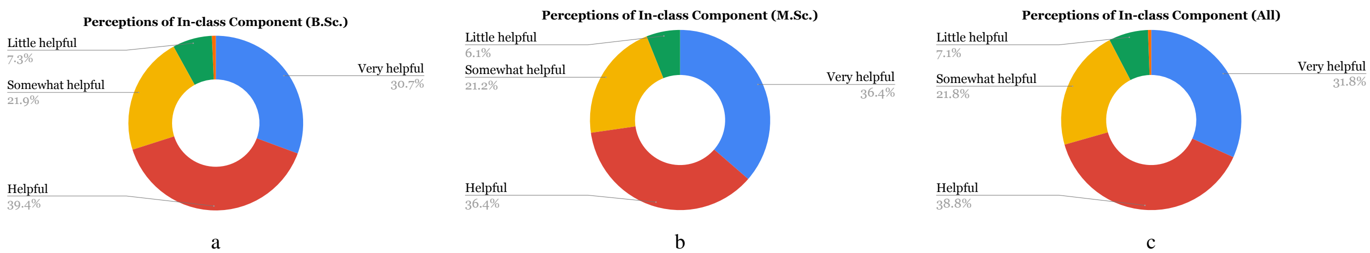


Fig. 7: Students' perceptions of the in-class component of the authentic learning-based exercise.

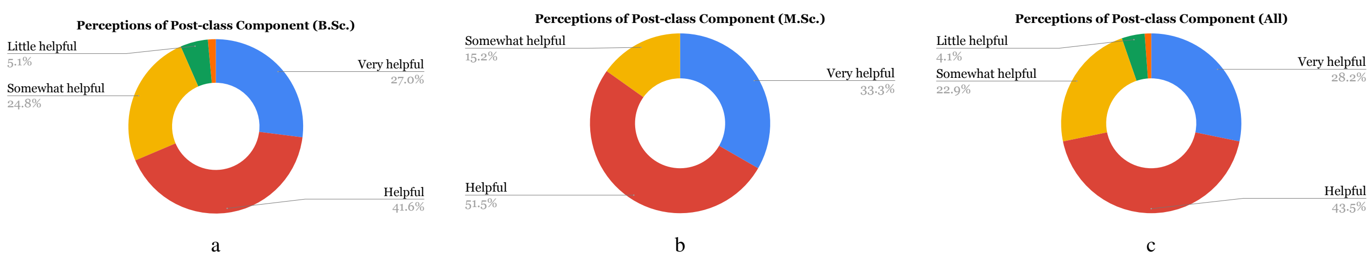


Fig. 8: Students' perceptions of the post-class component of the authentic learning-based exercise.

survey following Kitchenham's guidelines [17]. Results reported in Table I is susceptible to conclusion validity as other confounding factors related to learning experience may have not been included.

- **Internal Validity**: As the survey was conducted as part of an exercise for the course, students' biases and expectations related to the survey might impact the conducted analysis. We mitigate this limitation by not recording any personal information. Further, following the IRB protocol, we seek approval from each student prior to sending the survey.
- **External Validity**: Our findings might not generalize for students who are enrolled in other courses where information flow analysis is taught. If the authentic learning-based exercise is conducted at a different university, our results reported in Section IV may not generalize.

VII. Conclusion

Despite being perceived as an interesting topic, students face challenges when learning about information flow analysis. We have investigated if authentic learning is helpful for students to learn about information flow analysis. By deploying an authentic learning-based exercise with 170 students, we have observed authentic learning to be perceived as helpful by students. We observe perceived helpfulness for the authentic learning-based exercise to positively correlate with obtained grades. Based on our findings, to educate students about information flow analysis, we recommend instructors to: (i) develop authentic learning-based exercises, and (ii) consider the education level of students while designing individual components for authentic learning-based exercises.

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REFERENCES

[1] A. V. Aho, R. Sethi, and J. D. Ullman, "Compilers, principles, techniques," *Addison wesley*, vol. 7, no. 8, p. 9, 1986.

[2] M. Aniche, F. Hermans, and A. Van Deursen, "Pragmatic software testing education," in *Proceedings of the 50th ACM Technical Symposium on Computer Science Education*, 2019, pp. 414–420.

[3] ast, "ast–Abstract Syntax Tree," https://docs.python.org/3/library/ast.html, 2022, [Online; accessed 18-Sep-2022].

[4] M. Attariyan and J. Flinn, "Automating configuration troubleshooting with dynamic information flow analysis," in *9th USENIX Symposium on Operating Systems Design and Implementation (OSDI 10)*, 2010.

[5] A. Authors, "Replication package for the paper," 01 2024. [Online]. Available: https://figshare.com/s/e3a4dd5d3a5b65c43f5b

[6] S. Bekrar, C. Bekrar, R. Groz, and L. Mounier, "A taint based approach for smart fuzzing," in *2012 IEEE Fifth International Conference on Software Testing, Verification and Validation*. IEEE, 2012, pp. 818–825.

[7] J.-F. Bergeretti and B. A. Carré, "Information-flow and data-flow analysis of while-programs," *ACM Transactions on Programming Languages and Systems (TOPLAS)*, vol. 7, no. 1, pp. 37–61, 1985.

[8] D. O. Bruff, D. H. Fisher, K. E. McEwen, and B. E. Smith, "Wrapping a mooc: Student perceptions of an experiment in blended learning," *Journal of Online Learning and Teaching*, vol. 9, no. 2, p. 187, 2013.

[9] J. Dermo, "e-assessment and the student learning experience: A survey of student perceptions of e-assessment," *British Journal of Educational Technology*, vol. 40, no. 2, pp. 203–214, 2009.

[10] J. Duraes, H. Madeira, J. Castelhano, C. Duarte, and M. C. Branco, "Wap: Understanding the brain at software debugging," in *2016 IEEE 27th International Symposium on Software Reliability Engineering (ISSRE)*, 2016, pp. 87–92.

[11] W. Enck, P. Gilbert, S. Han, V. Tendulkar, B.-G. Chun, L. P. Cox, J. Jung, P. McDaniel, and A. N. Sheth, "Taintdroid: an information-flow tracking system for realtime privacy monitoring on smartphones," *ACM Transactions on Computer Systems (TOCS)*, vol. 32, no. 2, pp. 1–29, 2014.

[12] E. Enoiu, G. Tukseferi, and R. Feldt, "Towards a model of testers' cognitive processes: Software testing as a problem solving approach," in *2020 IEEE 20th International Conference on Software Quality, Reliability and Security Companion (QRS-C)*, 2020, pp. 272–279.

[13] P. Henrique Dias Valle, A. M. Toda, E. F. Barbosa, and J. C. Maldonado, "Educational games: A contribution to software testing education," in *2017 IEEE Frontiers in Education Conference (FIE)*, 2017, pp. 1–8.

[14] N. Herrmann and J. L. Popyack, "Creating an authentic learning experience in introductory programming courses," *SIGCSE Bull.*, vol. 27, no. 1, p. 199–203, Mar. 1995. [Online]. Available: https://doi.org/10.1145/199691.199780

[15] J. M. Hilbe, *Logistic regression models*. Chapman and hall/CRC, 2009.

[16] D. W. Hosmer Jr, S. Lemeshow, and R. X. Sturdivant, *Applied logistic regression*. John Wiley & Sons, 2013, vol. 398.

[17] B. A. Kitchenham and S. L. Pfleeger, *Personal Opinion Surveys*. London: Springer London, 2008, pp. 63–92. [Online]. Available: https://doi.org/10.1007/978-1-84800-044-5_3

[18] D. C.-T. Lo, K. Qian, W. Chen, H. Shahriar, and V. Clincy, "Authentic learning in network and security with portable labs," in *2014 IEEE Frontiers in Education Conference (FIE) Proceedings*, 2014, pp. 1–5.

[19] M. M. Lombardi and D. G. Oblinger, "Authentic learning for the 21st century: An overview," *Educause learning initiative*, vol. 1, no. 2007, pp. 1–12, 2007.

[20] J. S. Long and J. Freese, *Regression models for categorical dependent variables using Stata*. Stata press, 2006, vol. 7.

[21] F. W. Maina, "Authentic learning: Perspectives from contemporary educators," 2004.

[22] B. Mathis, V. Avdiienko, E. O. Soremekun, M. Böhme, and A. Zeller, "Detecting information flow by mutating input data," in *2017 32nd IEEE/ACM International Conference on Automated Software Engineering (ASE)*. IEEE, 2017, pp. 263–273.

[23] K. Qian, D. Lo, R. Parizi, F. Wu, E. Agu, and B.-T. Chu, "Authentic learning secure software development (ssd) in computing education," in *2018 IEEE Frontiers in Education Conference (FIE)*, 2018, pp. 1–9.

[24] A. Rahman and C. Parnin, "Detecting and characterizing propagation of security weaknesses in puppet-based infrastructure management," *IEEE Transactions on Software Engineering*, vol. 49, no. 06, pp. 3536–3553, jun 2023.

[25] A. Rahman, S. Hossain, and D. B. Bose, "Exercise perceptions: Experience report from a secure software development course," in *International Conference on the Quality of Information and Communications Technology*. Springer, 2021, pp. 521–535.

[26] A. Rahman, H. Shahriar, and D. B. Bose, "How do students feel about automated security static analysis exercises?" in *2021 IEEE Frontiers in Education Conference (FIE)*, 2021, pp. 1–4.

[27] A. Rahman, S. I. Shamim, D. B. Bose, and R. Pandita, "Security misconfigurations in open source kubernetes manifests: An empirical study," *ACM Trans. Softw. Eng. Methodol.*, vol. 32, no. 4, may 2023. [Online]. Available: https://doi.org/10.1145/3579639

[28] A. Rahman, S. I. Shamim, H. Shahriar, and F. Wu, "Can we use authentic learning to educate students about secure infrastructure as code development?" in *Proceedings of the 27th ACM Conference on on Innovation and Technology in Computer Science Education Vol. 2*, ser. ITiCSE '22. New York, NY, USA: Association for Computing Machinery, 2022, p. 631. [Online]. Available: https://doi.org/10.1145/3502717.3532125

[29] A. Rahman, Y. Zhang, F. Wu, and H. Shahriar, "Student perceptions of authentic learning to learn white-box testing," in *Proceedings of the 55th ACM Technical Symposium on Computer Science Education V. 2*, ser. SIGCSE 2024. New York, NY, USA: Association for Computing Machinery, 2024. [Online]. Available: https://doi.org/10.1145/3626253.3635584

[30] I. Richardson, L. Reid, S. B. Seidman, B. Pattinson, and Y. Delaney, "Educating software engineers of the future: Software quality research through problem-based learning," in *2011 24th IEEE-CS Conference on Software Engineering Education and Training (CSEE&T)*. IEEE, 2011, pp. 91–100.

[31] T. J. Shuell and S. L. Farber, "Students' perceptions of technology use in college courses," *Journal of Educational Computing Research*, vol. 24, no. 2, pp. 119–138, 2001.

[32] K. Struyven, F. Dochy, and S. Janssens, "Students' perceptions about evaluation and assessment in higher education: A review," *Assessment & evaluation in higher education*, vol. 30, no. 4, pp. 325–341, 2005.

[33] J. Van Brummelen, V. Tabunshchyk, and T. Heng, ""'alexa, can i program you?": Student perceptions of conversational artificial intelligence before and after programming alexa," in *Interaction Design and Children*, ser. IDC '21. New York, NY, USA: Association for Computing Machinery, 2021, p. 305–313. [Online]. Available: https://doi.org/10.1145/3459990.3460730

[34] M. R. Veall and K. F. Zimmermann, "Pseudo-r2 measures for some common limited dependent variable models," *Journal of Economic surveys*, vol. 10, no. 3, pp. 241–259, 1996.

[35] B.-D. Yoon and O. Garcia, "Cognitive activities and support in debugging," in *Proceedings Fourth Annual Symposium on Human Interaction with Complex Systems*, 1998, pp. 160–169.