UNIVERSITY OF CALIFORNIA SAN DIEGO

The Effect of Project Ownership on Student Approaches to Scientific Writing in an Upper Division Laboratory Course

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by

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The Thesis of Anqi Yang is approved, and it is acceptable in quality and form for publication on microfilm and electronically:

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TABLE OF CONTENTS

Signature Page..... iii

Table of Contents..... iv

List of Figures..... v

List of Tables..... vi

Abstract of the Thesis..... vii

Introduction..... 1

Methods..... 6
Data Collection..... 6
Survey Data Analysis..... 9

Results..... 12

Discussion..... 23
Student definition of project ownership..... 23
Student Approaches to Writing 26
Effect of project ownership on Student Approaches to Writing..... 30

Limitations and Future Directions..... 33

Appendix..... 35

References..... 41

LIST OF FIGURES

Figure 1. Common themes identified in open-ended survey responses from students regarding their definitions of project ownership. 12

Figure 2. Common themes identified in open-ended survey responses from students regarding positive effects of project ownership on writing..... 14

Figure 3. Student approach to writing the Introduction and Methods section of their scientific reports..... 17

Figure 4. Student survey responses to additional questions on their understanding of project materials and ethical responsibilities as authors..... 20

LIST OF TABLES

Table 1. Rubric used for coding student responses to Free Response Question, “How would you define ownership over a research project?” 10

Table 2. Rubric used for coding student responses to Free Response Question, “Do you think your sense of project ownership influences how you write your report?” 10

ABSTRACT OF THE THESIS

The Effect of Project Ownership on Student Approaches to Scientific Writing in an Upper Division Laboratory Course

by

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Student ownership of research experience is an important feature in STEM curriculum design that leads to the many documented outcomes, such as increased learning motivation, greater interest in research, and higher retention in STEM fields. Although previous researchers have derived concepts of ownership from student descriptions of research experiences, few studies examined the definition of ownership directly from students' perspective. In addition, we do not

have a clear idea of how student writing approaches relate to perceptions of ownership, particularly in a course-based research setting. To address these unknowns, we used qualitative analysis of student survey and interview responses in an upper-division laboratory course. Through the analysis of 167 survey responses and 9 interviews, we found that students have varying perceptions of ownership despite working on the same projects. Common themes of how students define ownership include *contributing ideas, doing the work,* and *being responsible for outcomes*. Regardless of the level of ownership students had, student approaches to writing were largely considered pragmatic, which relies on given ideas and secondary literature to dictate what to write, as opposed to the genuine approach, which builds writing on original thoughts. Despite efforts to increase ownership, other course structures may reduce the authorial identity students have and demonstrate. If our goal is to provide authentic research and writing experiences through a course-based laboratory setting, we need to carefully consider how scientific writing is incorporated, as well as how course structures support the development of ownership and authorial identity.

INTRODUCTION

Course-based undergraduate research experiences (CUREs) are research experiences incorporated into traditional high-enrollment undergraduate lab courses to create opportunities for a larger and more diverse group of students to engage in scientific inquiry and research (Sundberg et al., 2005; Wei and Woodin, 2011; Auchincloss et al., 2014). Although under lab course settings, these experiences involve students in real scientific research practices such as raising questions, proposing hypothesis, designing aspects of the research, collecting and analyzing data, interpreting results and communicating findings through scientific writing (Lopatto, 2003; Bruck et al., 2008; Weaver et al., 2008; Auchincloss et al., 2014). Other activities students may experience in CUREs include making discoveries in their areas of research, producing work relevant to the broader scientific community, conducting iterative work and collaborating with peers (Auchincloss et al., 2014). CUREs are alternatives to undergraduate research internship experiences (Wei and Woodin, 2011) and provide the many benefits that internships may bring to students. For example, CUREs help students develop greater understanding of course content (Lopatto, 2008; Rowland et al., 2012; Kloser et al., 2013; Olimpo et al., 2016), better analytical skills (Hanauer et al., 2012; Kloser et al., 2013; Brownell et al., 2015), more expert-like conceptions of scientific thinking (Brownell et al., 2015), higher self-efficacy (Brownell et al., 2012; Kloser et al., 2013), increased interest in research (Lopatto, 2008; Brownell et al., 2012) and retention in STEM education and career paths (Hanauer et al., 2012; Rodenbusch et al., 2016).

Despite the many positive outcomes students obtain from CUREs, what specific features in the design of CUREs lead to these outcomes are still being explored (Dolan, 2016). One possible feature is student project ownership. Previous literature has provided definitions of student

ownership of research projects. Wiley (2009) defined student ownership as a combination of *right and responsibility*, *buy-in* and *self-identification*. *Right and responsibility* refers to a student's personal responsibility when he or she has the right to make choices in the project and obtain consequential results. *Buy-in* refers to a student's contribution and engagement when he or she invests time, work or even money in the project. *Self-identification* refers to a student's personal connection and identification with the project when the student sees it as a representation or extension of his or her own experience (Wiley, 2009). Building on Wiley's work, Hanauer and colleagues (2012) further emphasized the element of *interaction* between student and the educational curriculum in project ownership. This interaction suggests that a student's ownership is not solely based on personal characteristics, but also affected by the educational curriculum he or she is in (Hanauer et al., 2012). Milner-Bolotin's study (2001) further revealed the dynamic nature of student project ownership. According to her findings, ownership over a project is not static, but changes throughout the research process as students obtain various cognitive and affective outcomes (Milner-Bolotin, 2001).

Studies have also looked into key aspects revealed from students' linguistic descriptions of research experiences that indicate the level of ownership they have over their research. The five major aspects are *personal agency*, *self-efficacy*, *peer interaction*, *positive affect*, and *relevance* (Hanauer et. al, 2012; Hanauer and Dolan, 2014; Stanley et. al, 2015). *Personal agency* means that a student actively sets goals for the research and seeks advice from others to reach those goals. *Self-efficacy* refers to a student's willingness and confidence in solving problems encountered during research process. *Peer interaction* is the collaboration among students. *Positive affect* refers to a student's expression of excitement and pride when making a scientific discovery or achievement. Finally, *relevance* means that a student perceives the research as relevant to his or

her personal interest or contribution to the larger scientific community. These five aspects were found to differentiate among different undergraduate research experience designs, and thus considered as hallmarks that indicate the level of ownership students have over their research (Hanauer et.al, 2012). Adding upon these hallmarks, Dounas-Frazer and colleagues (2017) proposed *cycles of struggle and success* as another necessary feature of successful research experience that would contribute to student ownership. During one cycle, students initially undergo feelings of frustration when facing obstacles in their research, but these feelings eventually turn into joy and satisfaction when moments of success arrive. This cycle may repeat several times during a research experience, through which students obtain greater enjoyment of the process, increased confidence in tackling challenges, and higher ownership in the experience (Dounas-Frazer et.al, 2017).

Project ownership can be fostered during CUREs due to the opportunities CUREs create for students to make their own independent contributions that affect the direction of the projects (Auchincloss et al., 2014). Project ownership may further serve as a mediating factor between CUREs and their student outcomes (Hanauer et al., 2012; Hanauer and Dolan, 2014). This proposed relationship has been supported by reasonable evidence from a few studies. For example, student ownership over a research project is positively correlated with student's learning motivation (Milner-Bolotin, 2001) and persistence in science education (Hanauer et al., 2012), and leads to higher student retention in pursuing STEM careers (Corwin et al., 2018).

Despite the many definitions and hallmarks of project ownership given by previous researchers, no study has investigated project ownership directly from students' point of view. The studies mentioned above either only provided definitions from experts in science fields or defined indicators that emerged from students' linguistic descriptions of experiences that can only

indirectly reveal their feelings of ownership. As a result, we are curious about what students' perception on project ownership is and how their definitions of ownership compare to expert definitions in literature and previously identified indicators in student descriptions.

Furthermore, although there have been some investigations into the relationship between ownership and student outcomes in CUREs, few related studies have examined the effects project ownership may bring to students' approach to scientific writing. Writing is an essential part of learning science, and communicating findings is an important part of a research experience. Students become more cognitively engaged when building connections among information in their written pieces, and thus obtain increased control over topics they write about (Martin et al., 1976). On the other hand, students get more connected to the broader science community through familiarization with disciplinary discourse (Berkenkotter et al., 1988). This process of building connections among ideas, texts, authors and across domains and disciplines creates new meanings of previously obtained knowledge and facilitates students' knowledge construction (Nelson, 2001). Through writing in science, students gain benefits such as better comprehension of course content (e.g., Kirkpatrick and Pittendrigh, 1984; Horton et al., 1985; Thall and Bays, 1989), greater personal connection to assigned reading (Reynolds and Pickett, 1989), increased interest in topics (Wäschle et al., 2015), familiarization with the culture of science disciplines (Martin et al., 1976; Berkenkotter et al., 1988; Carter et al., 2007) and larger connection to the science community (Carter et al., 2007). All of these benefits associated with scientific writing may contribute to the student outcomes obtained from CUREs.

In our previous research on student scientific writing, we implemented a plagiarism intervention in an undergraduate upper-division laboratory course to study if the intervention effectively decreased unintended plagiarism problems in students' written scientific reports (Yang

et al., 2019). One of the lab projects students completed was a Site-directed Mutagenesis (SDM) project. The goal of the SDM project was to explore the effect of a promoter mutation on gene expression. Unlike other groups, one SDM group of students were not assigned with pre-determined mutations, but designed and synthesized mutations of their own interest. This freedom of choice might have led to greater student responsibility, which is an important concept stated in Wiley's definition of ownership (Wiley, 2009), and thus might increase student ownership in their project. Despite this small difference in freedom of choice, the rest of the project design was the same across SDM groups. We observed significantly fewer plagiarism problems in written scientific reports from the SDM group that had both freedom of choice and the intervention, compared to those with the intervention only (Yang et al., 2019). This unexpected decrease in plagiarism indicated that students were more likely to include original explanations and thoughts in their writing when designing and synthesizing their own mutations. Thus, we propose that students' opportunity to choose mutation of interest affects their scientific writing approach through increased project ownership. Further investigating the relationship between project ownership and scientific writing will increase our understanding of how CURE curriculum elements impact student outcomes.

In summary, we will address the following research questions in the current study:

1) How do students perceive ownership in a lab course?
2) What is the relationship between students' perceived sense of ownership and their approach to scientific writing?

METHODS

Data Collection

Data analyzed in this study were collected from an upper division biology laboratory course at a large, public R1 university, and was approved by our human research protections program (Project number 181885). The course focuses on theories and practices of recombinant DNA and molecular biology techniques. Students are assigned with four major lab projects throughout the course: Agarose Gel Electrophoresis, PCR Variations, Ligation/transformation Efficiency and Site Directed Mutagenesis. In the Agarose Gel project, students use gel electrophoresis to determine the sizes and concentrations of two DNA samples. In the PCR variation project, students use PCR to amplify two different genes and test the effects of varying component of PCR on product yield. In the ligation/transformation Efficiency project, students clone genes from one organism, express those genes in a different organism, and screen the clones for ligation efficiency. Finally, in the Site Directed Mutagenesis project, students use mutagenesis to design different promoter mutants and investigate the effect of promoters on gene expression. Unlike the other three where the experimental conditions were much more constrained, the Site Directed Mutagenesis (SDM) project allows students to manipulate experimental conditions by designing mutations of their own interest, and the outcome of the different mutations is unknown to students and instructors, further adding a sense of discovery. We hypothesize that these factors give students greater ownership over the project. Students write a short (1-3 pages) scientific report for each of the four projects. These reports have the basic components of a scientific paper, including an introduction, a brief overview of the methods, results, and discussion. All of the reports are graded and feedback on their writing is provided.

Survey Data

At the end of the quarter, anonymous surveys were conducted to collect students' opinions regarding how they defined project ownership, the level of ownership they felt over their four lab projects, and their corresponding approaches when writing scientific reports. All students enrolled in the course were invited via an email link sent through the course management system, and the survey was distributed through Qualtrics platform. Students who completed the survey were offered extra credits. Those who did not wish to complete the survey were provided an opportunity to complete an alternative assignment for extra credits (see Appendix 1 for alternative assignment document).

The survey was designed and modified based on our findings of a previous study (Yang et al., 2019), in which we obtained a general idea of what changes project ownership might bring to student mindset about writing. The survey consisted of 14 questions in total, in the form of 5 free responses, 5 likert scale questions, 2 ranking questions, and 2 multiple choices. The students were first asked to define project ownership in their own words. Then, based on our given definition of ownership, they ranked the four lab projects in this course from the most ownership they felt to the least. From there, students were randomly divided into two groups. One of the groups completed the rest of the survey based on their most ownership project, while the other group were asked about their least ownership project. The questions used for the two groups were exactly the same. These questions focused on students' writing methods and different sources they used when writing the Intro, Methods, Results, and Discussion section of the report respectively. We tested the survey with a preliminary group of students taking the same course from a previous quarter (Spring 2018). Based on the preliminary results, we further adjusted the wording and order of

survey questions to reduce misinterpretations. A detailed version of the survey can be found in the Appendix (Appendix 2).

A total of 167 survey responses were collected from 4 course sections taught by 4 different instructors (37, 31, 62, 37 respondents from each section), with 85 responses in the most ownership group, and 82 responses in the least ownership group.

Interview Data

Post - survey interviews were also conducted to obtain supplemental information to assist the understanding of our students' survey responses. The interview questions were mostly the same as those on the surveys, but after each response, the interviewer (AY) also asked a series of follow-up questions to elicit further elaboration from the students. Examples of follow-up questions include but are not limited to: "Why did you choose that option?" "Could you explain this in more detail?" "What do you mean by …?" All students enrolled in the course were invited to the interview via an email link sent through the course management system. All interviews were anonymous and voluntary. Those that participated were given $15 cash. In the end, a total of 9 students were interviewed on a first come first serve basis.

Survey Data Analysis

Free Response Questions

Using an iterative approach, two of the researchers (AY and LM) designed rubrics to identify common themes that appeared in student responses to our 6 open ended questions, one rubric for each question. First, a random set of 20 survey responses were analyzed independently to come up with common themes, including frequently identified words and descriptions, in student responses. Both coders agreed that the rubric was appropriate, and so a second set of 20 responses were randomly chosen and examined independently by AY and LM. The coders then met and added clarifying definitions to the rubric to improve consensus. Prior to discussion, the two coders achieved 92% - 97% similarity in coding student responses using the rubrics. With discussion a 100% consensus was reached, and AY coded the remaining responses. Table 1 and 2 show the final rubrics used for two of the free responses (Q1 and Q14). The rubrics for the other 4 questions can be found in Appendix (Appendix 3 - 6).

Table 1. Rubric used for coding student responses to Free Response Question, "How would you define ownership over a research project?"

Q1. How would you define ownership over a research project?		
Common themes		Frequently identified words and descriptions
Category 1	Having one's own idea	Coming up with hypothesis; Experimental design; Procedure planning; Make decisions; Control direction of the project
Category 2	Putting in the work necessary for the project	Conducting experiment; Analyzing data; Drawing conclusions; Writing reports/papers
Category 3	Project leadership	organizing; leading; the "boss"; guiding other researchers
Category 4	Responsibility	Responsible for one's choices; Responsible for outcomes of the project
Category 5	Originality	Using one's own data; no plagiarism; giving credits to outside sources
Category 6	Funding	Provide funds; Research institution is usually mentioned

Table 2. Rubric used for coding student responses to Free Response Question, "Do you think your sense of project ownership influences how you write your report?"

Q14. Do you think your sense of project ownership influences how you write your report?		
Category 1	Personal connection	The material being more personal; feeling more responsible; caring more; more attached; representing oneself
Category 2	Positive feelings towards the project and oneself	Passionate; interested; confident
Category 3	Motivation	working harder; willing to put effort
Category 4	Freedom in writing	Having more to say; better discussion/explanation of results; unique writing; less reliance on rubric/lab manual
Category 5	Better understanding and more thinking	More comfortable with the material; easier to recall the process

Question 1 asked about students' own definitions of project ownership. Question 14 asked students if they think ownership can change their ways of scientific writing. We do not expect the responses to these two questions to differ between the most and least ownership groups, so the results were merged and reported as a whole.

The remaining four free response questions focused on students' approach to writing every section of their lab reports, and were expected to show a difference in responses depending on if students were reflecting on the most or least ownership project. Thus, we calculated the frequencies of each common theme from the student responses for both most and least ownership groups. Fisher's exact tests were conducted to measure the differences in common theme distribution between the two groups.

Multiple choice questions

The counts of choices for each likert scale and multiple choice question were recorded. Fisher's exact tests were conducted to measure the differences in choice distribution between most and least ownership groups.

RESULTS

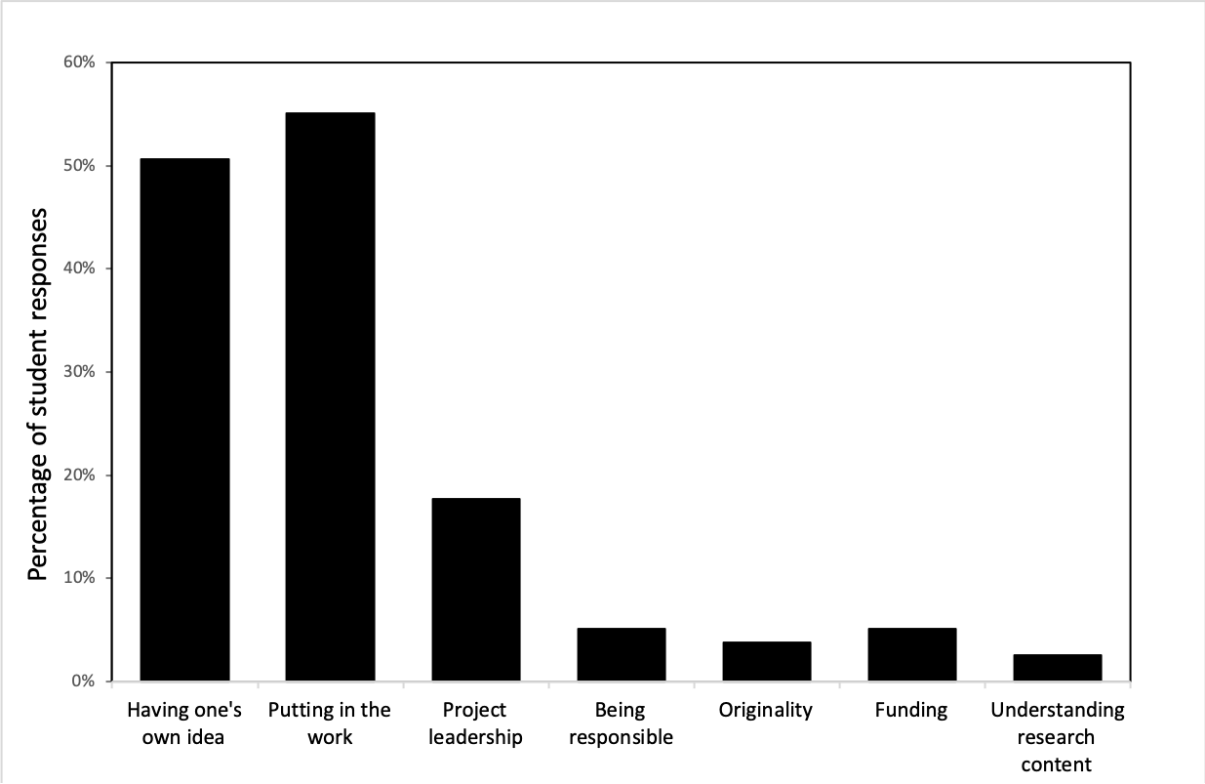


Figure 1. Common themes identified in open-ended survey responses from students regarding their definitions of project ownership. A total of 158 student responses were coded. The response from an individual student can contain multiple themes. Therefore, the total percentage of student responses can be above 100. The two most frequently given definitions in student responses are *putting in the work necessary for the project* (55% of student responses) and *having one's own idea in the project* (51% of student responses).

To learn about the definition of project ownership directly from students' perspective, we asked an open-ended question on the survey, "How would you define ownership over a research project?". Seven common themes were identified from student responses (Table 1). The two most frequently mentioned themes were *putting in necessary work* and *having one's own idea* (Figure 1). About 55% of the students considered the actual execution of the project as a contributing factor to ownership, as illustrated by the following example from survey responses,

> Ownership over the research project would be actually completing the experiments as well as analyzing the data.

About 51% of the students considered their own idea on the main research questions and procedure designs as an important factor that contributed to their feelings of ownership. According to these students, the autonomy in coming up with one's own hypothesis, creating protocols needed to conduct experiments and making major decisions was essential for them to feel ownership over their project. This was also echoed by one student's interview response,

> Ownership is like, if you have an experiment, how much of that experiment you are able to come up on your own or like have control over the design of the experiment.

Moreover, 20% of students mentioned both themes in their responses. Among those students, some acknowledged the necessity of both work and idea to fully claim ownership. For example, one student mentioned in the survey,

> [Ownership means] creating and performing your own set of guidelines for a project.

Other students, however, didn't specify this necessity. As one student in our interview pointed out,

> I do think that the person that really designed the research is the real owner, but I do feel like I have some ownership if I at least like participated and helped in the work of it.

In such cases, students felt ownership over their projects as long as they made contributions, either in the form of work or their original ideas.

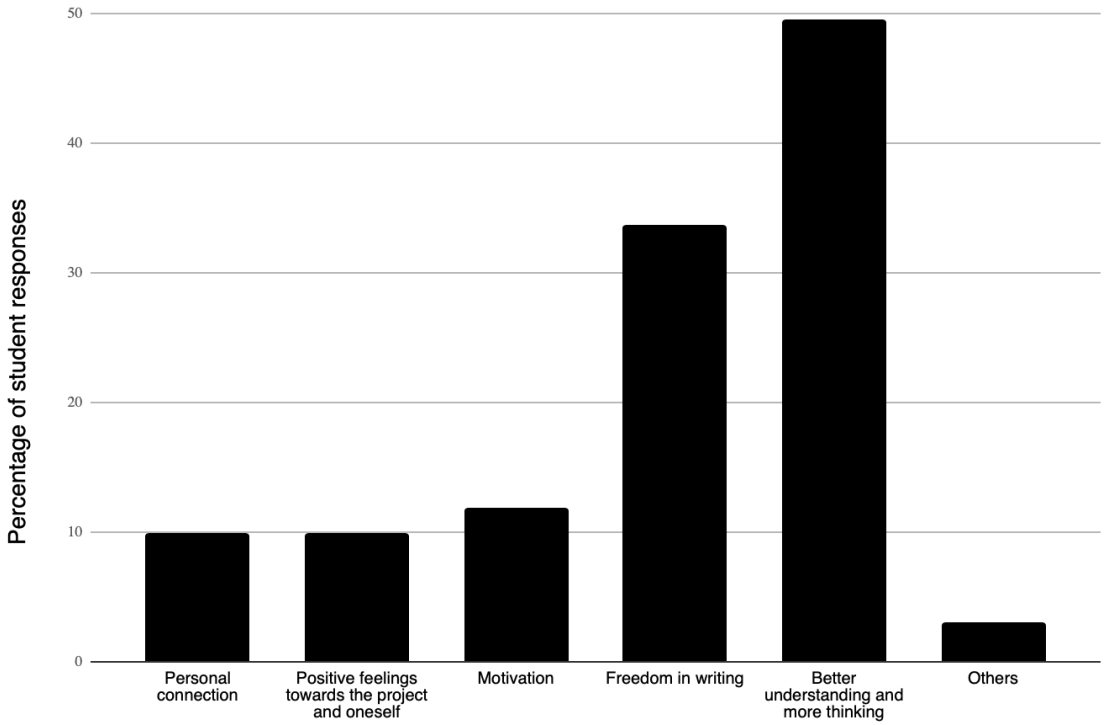


Figure 2. Common themes identified in open-ended survey responses from students regarding positive effects of project ownership on writing. A total of 167 student responses were coded. Shown here are 101 responses (64%) in which students reported positive effects of ownership on their writing. The response from an individual student can contain multiple themes. Therefore, the total percentage of student responses can be above 100. The two most frequently given effects of ownership are *creating better understanding and more thinking of the course material* (50% of student responses) and *providing freedom in writing* (34% of student responses).

We also asked the students if they think project ownership had any influence on their ways of writing scientific reports. About 64% of our 167 students thought that ownership has positively affected their writing approach. Five common themes were identified from these positive responses (Table 2). The two most frequently mentioned themes were *creating better understanding and more thinking of the course material* and *providing freedom in writing* (Figure 2). About 50% of the students reported that they gained deeper knowledge on the topics they wrote about if they had a feeling of ownership over the project. They felt more comfortable with the material, and it was also easier to recall the processes when writing the Methods section. About 34% of the students considered the freedom of writing an influential outcome of project ownership. According to these students, with this sense of freedom, they were able to better discuss and explain their own results. Their writing became more unique because they generally relied less on lab manual or rubric provided by instructors. The better understanding of lab material and the freedom in writing were also closely related. For example, one of the students further illustrated this relation in the interview,

> instead of just going into the motions, like you're really like a robot … and I don't know what I did, so how am I supposed to explain this … it feels good to understand why things are happening.

Other than these two categories focusing on students' comprehensive knowledge, we observed some more personal influences from ownership as well. About 10% of our students reported a connection between the project they worked on and themselves, which led to more attachment to their work and thus higher responsibility. Students also reported more positive feelings towards their projects and themselves. The personal connections and positive feelings gained during these projects were likely related to higher motivation, which was also observed in our data. As one student elaborated in the interview response,

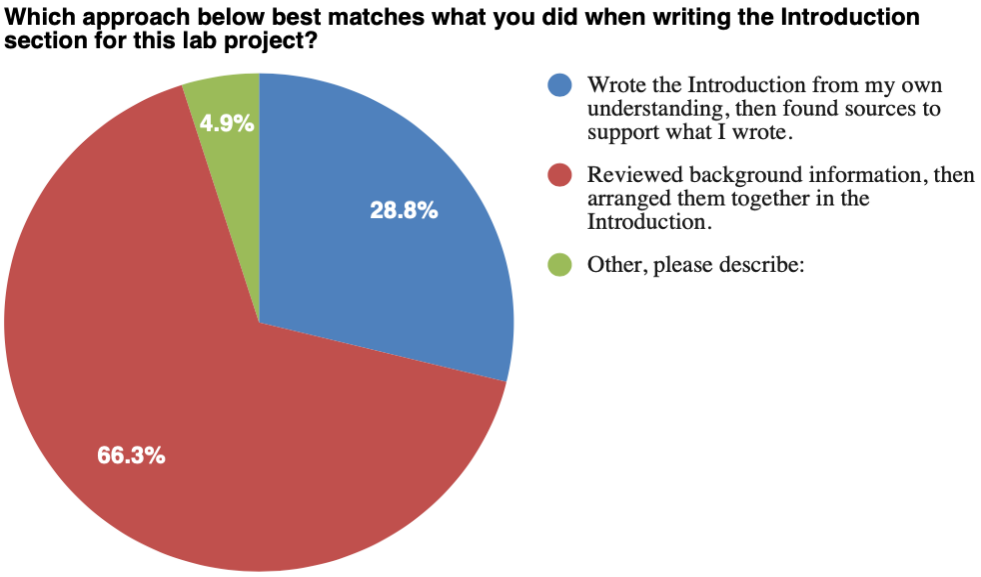
> You try harder … because I felt like I have more ownership… I've felt like I had almost a responsibility for me to work harder.

Another student from the interview, who found the project enjoyable, simply said,

> It's not really scary to write it, so I am willing to (put more time and effort into the writing).

About 25% of our students did not think the level of ownership affected their writing approach. Although these students did admit that personal connection, positive feelings and motivation were present in their research experience, the report guideline and their previously established writing style still ruled. They preferred following what they were used to, and did not bother making any changes just for this lab course.

a)



b)

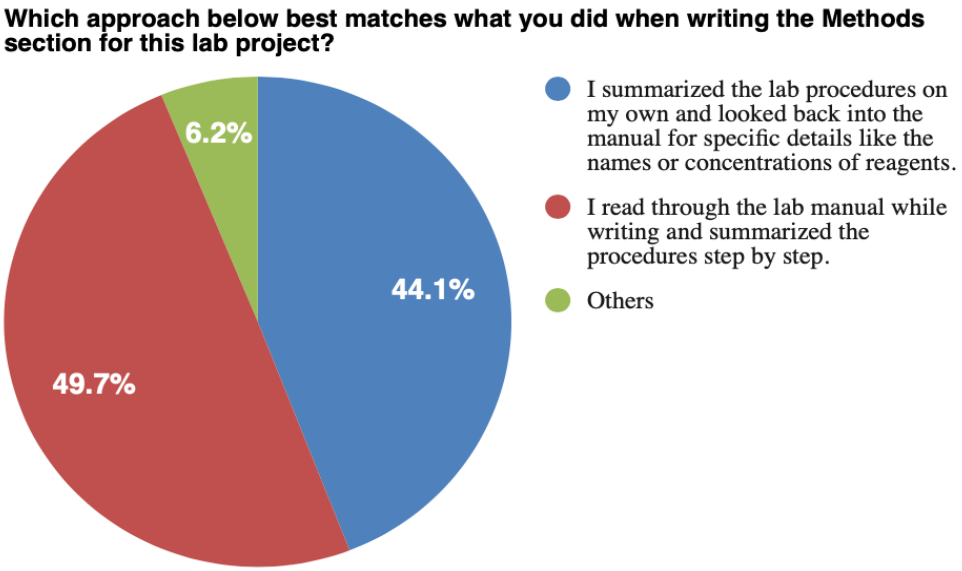


Figure 3. Student approach to writing the Introduction and Methods section of their scientific reports. A total of 167 student responses were analyzed. The results from the most and least ownership groups were combined because no significant difference was observed in the choice distribution between the two (Fisher's exact tests, $p>0.05$). **a)** Most of our students used the "bottom-up" method to write their Introduction section regardless of the ownership they have over their lab projects. **b)** A slightly higher percentage of students chose to rely on the lab manual more often when writing the Methods section.

Two multiple choice questions were given in the survey to ask about students' writing approaches for specifically the Introduction and Methods section of their lab reports. Unlike our expectation, there was no significant difference in approaches to writing the Introduction and Methods between the most and least ownership groups for both questions (Chi-square tests, $p>0.05$). Regardless of the ownership they have over lab projects, students used a more "bottom-up" approach when writing the introduction as opposed to the "top-down" approach (Figure 3-a). In short, most of them tended to read background literature, and then gather pieces of information they obtained from those literature together into an Introduction. When asked about why they chose this approach in the interviews, most students expressed a feeling of uncertainty to start the Introduction from their own understanding. As some interviewees explained in the responses,

> ... there was a lot of information, so I wanted to know what was necessary first before writing the lab report. And then that would be more specific, so I don't get things confused. ... just so I don't like write false things.

One of the interviewees, although quite confident about starting the Introduction on his own, described the "bottom-up" method as an easier and more practical way to write a lab report,

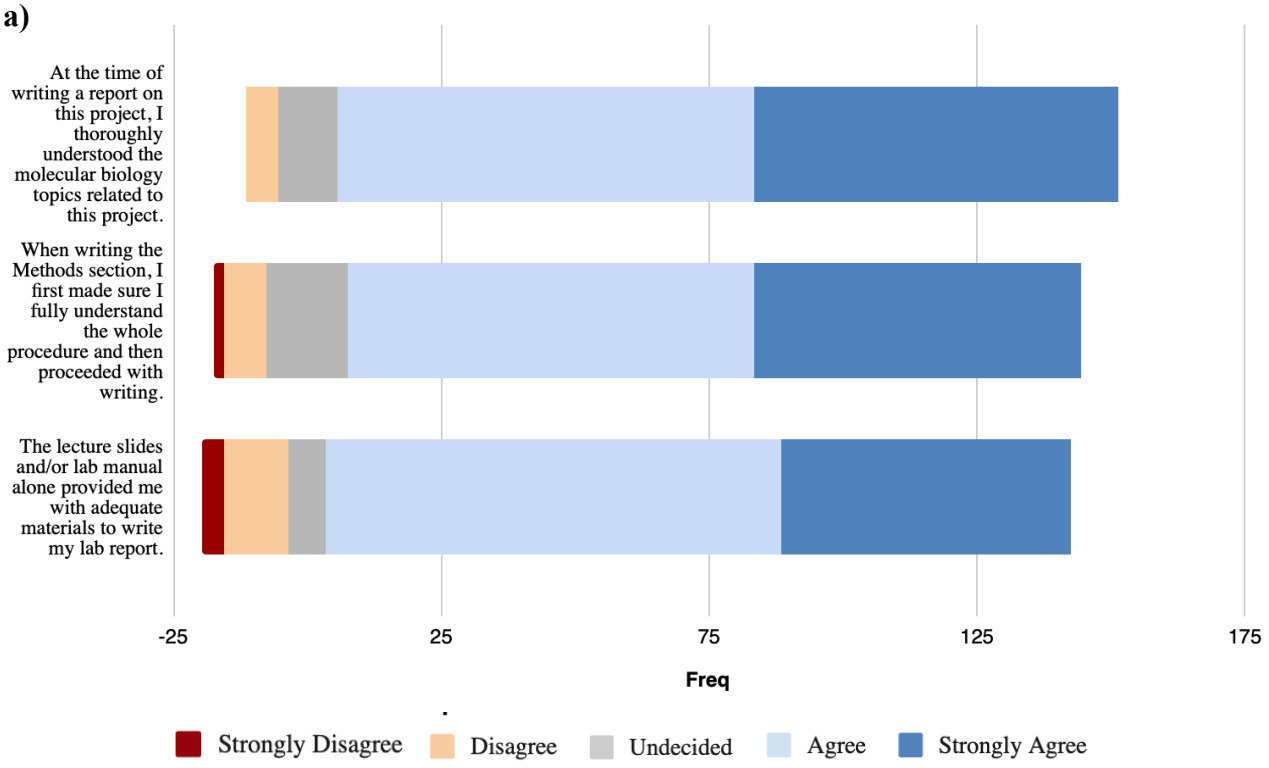
> There's a guideline about the lab report that say what I need to put in and then I just need to gather up information from in class and from my own material from another class, and then I put together to decide (what to put) into the introduction.

When writing the Methods section of the report, students didn't seem to have any evident preference for the approach they used (Figure 3-b), but a slightly higher number of students tended to rely on the manual more often. About 44% of the students chose to recall and summarize the procedures from their memories, and refer back to the lab manual only for small details such as reagent names or concentrations. When asked about why they chose this method during interviews, these students expressed a good understanding of the lab manual, and it was usually unnecessary for them to follow the manual for every step. About 50% of our students kept the lab manual by their hand, and went back and forth between their writing and the manual to summarize step by

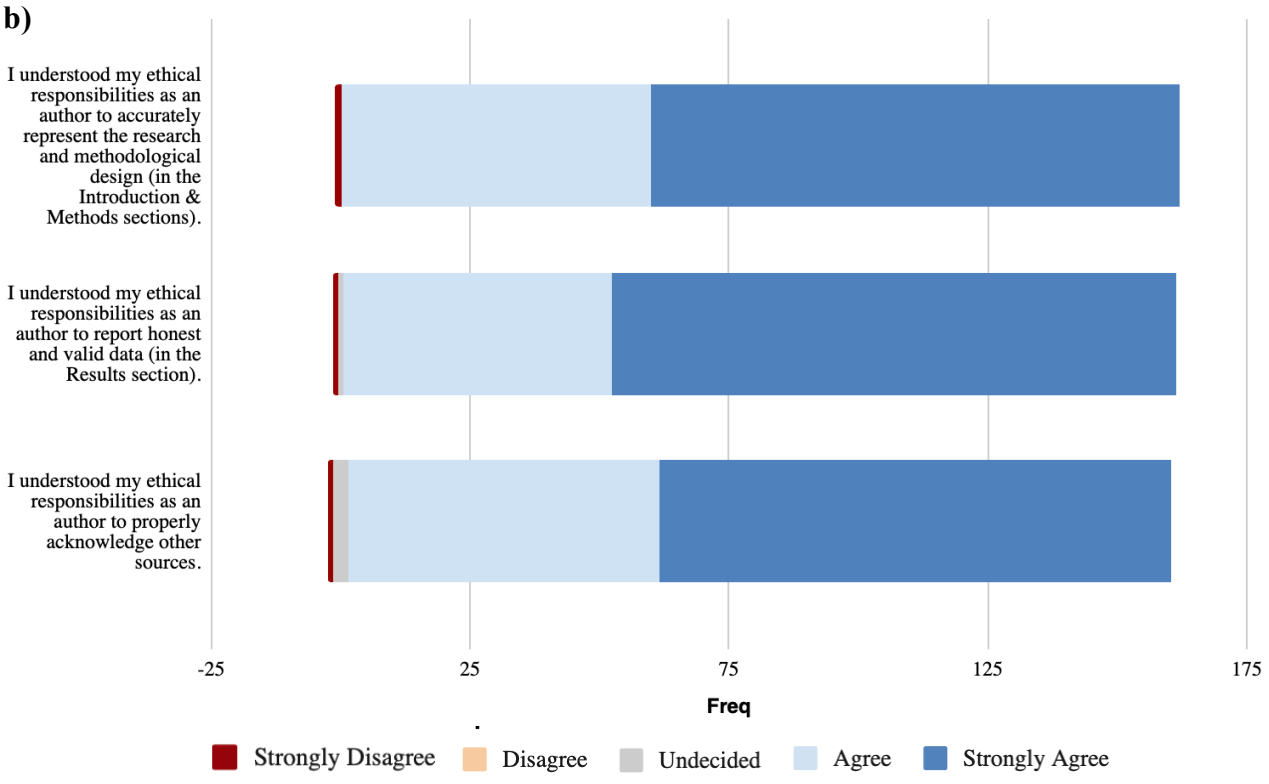
step. Similar to those who chose the “bottom-up” approach for writing the Introduction, students who rely more heavily on their manual for Methods were either not confident enough to recall every step from their memories or found this method way more efficient for finishing an assignment.

Figure 4. Student survey responses to additional questions on their understanding of project materials and ethical responsibilities as authors. A total of 167 student responses were analyzed. The results from the most and least ownership groups were combined because no significant difference was observed in the choice distribution between the two (Fisher's Exact Test, $p>0.05$). **a)** Most of the students thoroughly understood the project related topics and lab procedures at the time of writing. They also agreed that lectures and lab manuals alone provided sufficient knowledge to write their reports. **b)** Almost all of our students reported a good understanding of their ethical responsibilities as authors to accurately represent the research and methodological design, to report honest and valid data, and to properly acknowledge other sources.

a)


At the time of writing a report on this project, I thoroughly understood the molecular biology topics related to this project.
When writing the Methods section, I first made sure I fully understand the whole procedure and then proceeded with writing.
The lecture slides and/or lab manual alone provided me with adequate materials to write my lab report.
-25
25
75
125
175
Freq
Strongly Disagree
Disagree
Undecided
Agree
Strongly Agree

b)


I understood my ethical responsibilities as an author to accurately represent the research and methodological design (in the Introduction & Methods sections).
I understood my ethical responsibilities as an author to report honest and valid data (in the Results section).
I understood my ethical responsibilities as an author to properly acknowledge other sources.
-25
25
75
125
175
Freq
Strongly Disagree
Disagree
Undecided
Agree
Strongly Agree

Last but not least, we included 6 likert scale questions in the survey to get an idea of how well our students understand the course topics, lab procedures, and their ethical responsibilities as authors. These questions were asked because content understanding and authorial responsibilities may be influenced by ownership, and developing an authorial identity. Once again, there was no significant difference in choice distribution between the most and least ownership groups for any of the questions. As shown in the responses, most students agreed that they thoroughly understand the biological topics and lab procedures related to their projects before writing the lab report (Figure 4-a). Interestingly, one of the students that agreed with this statement in interview mentioned small confusions about concepts introduced in the course, and writing the report helped the student realize those confusions and dig back into the course material,

> If I did have minor questions, I would look at the lab or look at the manual or if they were like, if I still didn't understand it while I was writing it, I would ask the TA.

A majority of students also agreed that the lecture slides and lab manuals alone provided adequate material to finish their lab reports (Figure 4-a). In fact, lecture slides and lab manuals were the two major sources used by our students when writing. About 85% of students ranked either lecture slides or lab manuals as their top choices (data not shown). Primary literature was seldom used, unless they were asked by the instructors,

> (I didn’t use primary source) except for that one paper that asked for a primary source, then I used a primary source.
> I was required, I mean, if it wasn't required I probably won’t do it, coz it takes a lot of time to like go through different sources and see which one works well with the report and things like that.

Almost all of our students agreed that they understood their ethical responsibilities as authors (Figure 4-b). In fact, only 1 out of 167 students chose to strongly disagree. These responsibilities include accurately representing the research and methodological design, reporting honest and valid data, and properly acknowledging other sources.

DISCUSSION

Student definition of project ownership

To learn about the definition of project ownership directly from students' perspective, we asked students to describe project ownership in both surveys and interviews (Figure 1). One of the most common themes that arose from student responses was *having one's own idea in a project*. Specifically, when talking about incorporating their ideas, our students emphasized a necessity of autonomy in changing part of the project, such as coming up with original hypotheses, making their own predictions, designing experimental conditions and manipulating experiment methodology. This right to make choices that control the overall direction of a task is defined as one aspect of the *right and responsibility* category in Wiley's definition of ownership (2009). It is also this right to control that leads to a sense of authority in students, and thus promotes ownership over the task (Wiley, 2009). Another important aspect of the *right and responsibility* conceptual category of ownership is a sense of responsibility which arises together with students' freedom of control, because students are now partly in charge of the research process and thus responsible for the results obtained from that process (Wiley, 2009). However, few students in our survey (5%) stated the responsibility for their choices when describing project ownership (Figure 1). The generally small concerns on consequences of choices in our students is possibly due to the low stakes they had when making decisions under a traditional lab course setting, since their research outcomes are usually not needed beyond the scope of a course (e.g. for a publication), which makes the whole experience less related to the real scientific community.

Another common theme in our students' definitions of ownership was *putting in the necessary work* regardless of degree of involvement, which is consistent with the *buy-in* category in Wiley's definition (2009). *Buy-in* means that an individual spends time and effort on a task, but

the degree of investment varies among individuals. One can be fully committed to a task and thus has a high personal intensity of engagement, or just passively decides to participate but does not put much energy into the task. In either case, the individual may claim ownership (Wiley, 2009). Likewise, our students value their time and effort invested in a project. Some of our students thought that only those who were highly devoted to their projects and did continuous work should claim ownership, as illustrated by one student in the survey,

> Ownership indicates that a certain individual has performed a majority of the background research, all the protocol/analyses and data retrieval of the project.

Others felt they should claim some ownership even if they were just passively or partially participating, as one student explained in the interview,

> Even if you didn't like write anything, you just made like a figure, (you have ownership over a research project).

In Wiley's definition of ownership, there is a third conceptual category, ownership as *identifying with*, which is defined as the personal identification a student has with a task when the task extends from his or her previous experiences or is relevant to personal interests (Wiley, 2009). However, none of our students have ever mentioned any form of personal connections with the project in their definitions. This is within our expectation. Since the big research topics of the projects in our lab course were all pre-determined, it was very unlikely that the projects extended from our students' previous experiences or individual interests. In addition, Wiley (2009) also pointed out that students' sense of personal connection heavily overlaps with the previous two conceptual categories, ownership as *right and responsibility* and ownership as *buy-in*, suggesting that autonomy in decision making and investment of work generally precede the final recognition of personal value in a task. Nevertheless, the level of autonomy and degree of investment our students experienced were likely not adequate for them to build personal connections with the projects they engaged in. Although students were given the opportunity to design mutations in the

SDM project, this was only a small step in the beginning of the entire research experience. During the rest of their experience, students still had limited freedom in making important decisions and controlling the direction of research. Furthermore, like in most traditional lab courses, the experimental procedures of our projects were pre-designed, and students were able to simply follow instructions from the lab manual, perhaps without high commitment.

Student Approaches to Writing

We focused on student approaches to writing the Introduction and Methods section of their scientific reports, because student plagiarism and writing problems were more commonly found in these two sections from our previous research (Yang et al., 2019). We hypothesized that with more ownership, students are more likely to use genuine approaches which include more original ideas, because the level of autonomy and investment from ownership help establish student authorial identity. We conducted two multiple choice questions covering the major types of approaches identified from preliminary surveys (data not shown). The impact of lab content comprehension on writing could not be determined from our students' responses, since most students agreed that they thoroughly understand the biological topics and lab procedures related to their projects before writing the lab report (Figure 4-a).

We identified two common approaches to writing the Introduction from our preliminary research surveys: "top-down" and "bottom-up". The "top-down" approach, considered deeper and more authentic writing, starts from one's own thoughts (Elander et. al, 2017). With major concepts and ideas in mind, students look for sources to support the arguments they constructed in their writing. The "Bottom up" approach, on the contrary, starts from available source materials. This approach is described as more superficial (Elander et. al, 2017). Students look for pieces of information from different sources, and organized sources together to form an Introduction. We expected our students to use a more "top-down" approach if they were writing about the project they have more ownership over, since ownership is coupled with student agency, students should have more control over the entire project and thus feel that it is easier to come up with ideas that belong to themselves. However, our data did not report any significant difference between the most and least ownership groups. Overall, about 66.3% of the students still chose the "bottom-up"

approach; this is about twice as much as those who used the "top-down" approach. Generally, students found this approach more time-saving and practical. According to one student from interviews, using the "bottom-up" approach means he didn't have to construct a main idea until he finished part of the Introduction. The usage of "bottom-up" approach is coupled with some adoption of pragmatic writing approach, such as using more secondary literature (lecture slides, background information from lab manual), and answering questions on lab report guidelines one by one to form into the Introduction. These pragmatic approaches to writing are usually strategies used by students to improve course grades and eliminate effort (Elander et.al, 2017).

For the Methods section, we also identified two commonly used writing approaches from preliminary surveys: "Summarizing on their own" and "Relying on the manual". "Summarizing on their own" approach requires students' own summarization of the lab procedure with little assistance from the lab manual. This can be viewed as a more authentic writing approach, because in reality, scientists do not have manuals to refer to. "Relying on the manual" approach is more of a "copy, edit and paste" process. This more pragmatic approach likely leads to one writing problem commonly found in Methods: *Technical parroting* (Bertram Gallant et al., 2019). *Technical parroting* has been a debatable issue among instructors. Some instructors argue that there are not too many unique ways to describe a pre-designed lab procedure. However, we did observe a decent number of students being able to complete the Methods section with very few technical parroting issues in our previous research (Yang et al., 2019). In order to prevent copying, editing and pasting from lab manual, students need to have a big picture understanding of the overall experimental process. Surprisingly, even though most of our students reported a full understanding of the lab procedure before writing (Figure 4), a slightly greater number of students still chose to rely on the manual heavily. Interviewees admitted that this "manual heavy" approach is more time-saving and

practical. The high usage of secondary literature creates an easy and lower-effort strategy for students to complete the Methods section while maximizing chances of receiving course credits.

There are several possible reasons as to why most of our students chose to use more pragmatic but superficial approaches rather than genuine approaches to scientific writing. First of all, the level of ownership students gained may not enough for them to perceive this course as an authentic research experience. As discussed above, allowing students to design mutations of interest in the Mutagenesis project was one fairly small change when taking the entire project into account. The presence of a pre-written, detailed lab manual further lowered student ownership; since most of the procedure was given in the manual, it largely restricted the need for students to choose methods and engage in experimental design by themselves, which might be necessary for greater ownership. As a result, although the SDM project might be more interesting to work on compared to the traditional project, which contained less choice, students still viewed the project as part of a basic lab course. We also have to take the course structure into account. The course consists of multiple projects with different topics, each of which lasts about several weeks. Such high pace made it less likely for students to fully commit to the process. As commented by some students, they often had to prepare for the next project while still writing about the previous one. In this case, using the most time-saving way to write the reports seems a reasonable choice.

Secondly, since this is an upper division lab course, most of our students have already participated in multiple lab courses and some have also worked in real labs. It is very likely for the students to establish writing habits throughout different previous lab experiences. In fact, one of the interviewees expressed a slight reluctance to change his writing habits that worked best for him. Meanwhile, the students were provided with a written guideline pointing out the major contents to include in their reports, as well as a grading rubric explaining how credits will be given

in detail. Such detailed guidelines may limit students' writing approach, perhaps sabotaging any opportunities to develop more ownership over the writing. Students expressed a high reliance on the guideline. Two of the interviewees tried answering the questions on the guideline one by one, and put the answers together to form an Introduction. Students simply wanted to make sure they got as many credits as possible for the overall course score.

One unexpected reason discovered from interviews was that students did not feel well-equipped with knowledge to write the Intro and Methods independently. Their concern was that they might make mistakes when describing any background information and lab procedures on their own. Uncertainty in students can be common as they get exposed to more complicated techniques and more professional writing after reaching upper division. Having literature from experts by hand might bring them relief.

In short, the small change we made in one single project isn’t sufficient enough to have significant impact on student writing approaches to the Introduction and Methods section in their lab reports. Many other factors, such as course structure, course content and student past experience may also affect the approaches they chose to use. Perhaps our students did enjoy the SDM project more than the other ones, but when it comes to lab reports, students don’t mind using their good old ways of writing.

Effect of project ownership on Student Approaches to Writing

Now that we explored students' definition of project ownership and the approaches they take when writing reports, we are also interested in if there might be any connections between the two. More than half of our students (64%) reported positive effects of project ownership on their ways of writing (Figure 3). Because writing approaches to the Introduction and Methods did not differ significantly between the most and least ownership groups (Figure 2), we suspect that those positive effects from ownership were mainly on writing the Discussion section. Among students who reported positive effects, 50% thought they gained better understanding of course material, mostly because more critical thinking was involved in lab process; thus, they found it easier to write about what they've learned and done. The close connection between critical thinking, understanding and writing is already well-found. Previous studies focused mainly on how incorporation of writing exercise in science instruction assist critical thinking, better comprehension and deeper learning (e.g., Kirkpatrick and Pittendrigh, 1984; Horton et al., 1985; Thall and Bays, 1989, Elander et.al, 2010). Our results indicated that increased critical thinking is further related to project ownership. Possible bridges between the two could be higher responsibilities and positive emotions students feel towards their project. As explained by our interviewees, when owning a project, students feel obligations, and are more eager to thoroughly understand the project content. Furthermore, better comprehension of project content can be a major reason for the decrease in student plagiarism and writing problems found in our previous research (Yang et al., 2019). With a deeper understanding, it is easier for students to come up with original thoughts based on the sources they have instead of just paraphrasing ideas they obtained from other literature.

A freedom in writing is also frequently mentioned by students who agreed that ownership changed their ways of writing, especially for the Discussion section. This freedom was coupled with a personal connection established in the project. Indeed, personal connection is an important element of ownership (Wiley, 2009). As some of our interviewees indicated, students with feelings of ownership tended to view their writing as something more unique and meaningful rather than copies from people who did exactly the same thing, so they were more free to express original thoughts using their own words. According to one of our interviewees specifically, it was easier than expected to describe and explain unexpected data simply because he knew every group was going to obtain different results and he enjoyed sharing unique findings. This is encouraging, because although the overall project idea did not represent or extend from students' own experience, the freedom to manipulate a small but crucial experimental condition could greatly impact students' feeling towards what they were working on. Such freedom can be incorporated into large-scale, basic lab courses where personalized project is impractical to at least provide some personal impact on students and better motivate students to engage in the course.

Our students also reported positive feelings towards the project (e.g., "interesting", "meaningful", "enjoyable") and themselves (e.g., "confident" "well-prepared") gained from ownership. These positive feelings further led to student motivations to put time and effort into writing, as mentioned both in survey and interview responses. Previous study shows that initial interest of the project is not a necessary component for student project ownership. In fact, interest and values found in the project tend to increase as students get engaged in the process later on (Dounas-Frazer et. al, 2017). Although we did not look into the changes of student attitudes in our data, responses still indicated that positive feelings can be cultivated by ownership. Positive feelings are not constant throughout the project, either. Students show a wide range of emotions

shifting between negative and positive feelings as they experience moments of frustration and success, but reach an overall positive attitude eventually (Dounas-Frazer et. al, 2017). This eventual positive attitude can motivate students to further engage in the next phase of the project. In our case, higher engagement in the project was not limited to in-lab hands-on activity, but also extended to their writing.

Most impacts from ownership on writing reported by our students were in the Discussion section. Meanwhile, the actual approaches taken when writing Introduction and Methods did not change significantly (discussed in previous section). We expect writing of the Discussion section to have a more direct impact from ownership because it is where students explain their own findings and elaborate original ideas to readers based on unique data obtained. Less secondary literature is used as references. Coupled with ownership-promoting course design, less detailed instructions on writing the Discussion section (e.g. no guidelines) can be a good starting point to allow students to practice more original and genuine scientific writing.

LIMITATIONS AND FUTURE DIRECTIONS

Adding upon expert definitions of student ownership given by previous researches (Wiley, 2009; Hanauer et al., 2012), our study further provides insights about conceptual categories in the definition of ownership directly from students' perspective. However, students who participated in our research were all from the same upper division biology lab course, and thus their responses might be limited by the course setting. Future studies may look into the definitions provided by students from research experiences designed to promote different levels of ownership, such as CUREs where students design the entire research project (Auchincloss et al., 2014), or undergraduate research apprenticeships where students engage in authentic research under individual faculty members' laboratories (Wei and Woodin, 2011). This additional investigation would better examine student ownership definition under different research experience settings, determine if the conceptual categories of their definition are different among the various experiences, and evaluate if they are consistent with those from experts. Extending from those comparisons, researchers may also examine if there are specific moments or aspects in research experiences that help shape students' definition of ownership.

Another major limitation of this study was that the topics of the two projects which students felt most and least ownership over were different. Most students ranked the Mutagenesis project as the one with most ownership (66.3%), while the Agarose Gel one as the least (65.7%). Not only did the Mutagenesis project require deeper understanding of multiple biology contents, but it also involved a more complicated procedure with more steps and a longer lasting time period. Meanwhile, the Agarose Gel project was more of an introduction to the course, helping students become familiar with the course structure and get some hands-on practice on a basic lab technique. It did not require as much time and effort as the Mutagenesis project. Thus, it wasn't ideal to

compare students' comprehension of contents, writing approaches and overall attitudes regarding these two projects. This could also be a reason why we didn't observe significant differences in writing the Introduction and Methods section between the most and least ownership groups. Future studies may control for the project topics but change the lab designs to better investigate if such changes alone can significantly affect student project ownership and their corresponding approach to writing.

Lastly, we only focused on students' perceived ways, but not the actual approaches they took when writing the Discussion. All the freedom and changes in writing brought by project ownership were reported from students' subjective descriptions of their experience. Whether ownership really affected their Discussion writing remains unknown. Further studies may design survey questions similar to those we used for Introduction and Methods writing to get a more objective view of how students approach their Discussion section. Similarity-detection software, such as Turnitin®, can be used for systematic detection of original or "borrowed" ideas students include in their Discussion writing. We may also count the number of primary literature citations to investigate how often students look for outside sources instead of secondary literature to support their ideas. Differences found in these practices shall provide insight on how exactly project ownership helps create a freedom in writing as experienced by many of our students.

APPENDIX

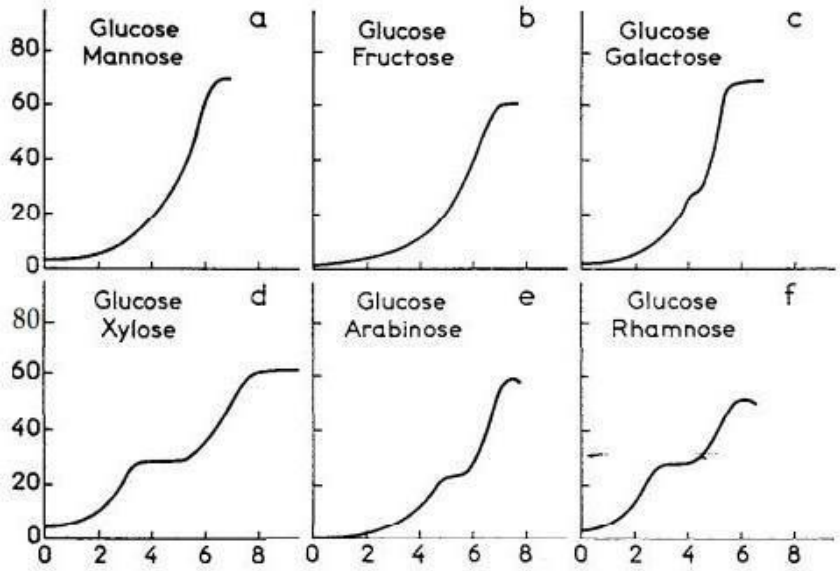
Appendix 1. Alternative Assignment

Completion of this assignment will be awarded a bonus point (note, only one bonus point per student: either completion of the survey or this assignment).

Assignment Instructions:

- Analyze the data below and write a scientific argument to summarize what you can conclude about the relationship between sugar source and metabolism. Your argument should contain a claim (what you can conclude), a description of the data/evidence that supports your claim, and an explanation (a possible biological mechanism or hypothesis to explain why and how this relationship exists).
- Type up your assignment, and then paste it into the answer field by following this link: https://goo.gl/forms/bnFdFeOEsk6AGdHz1
- To receive the bonus point, the assignment must be completed by December 11, 2018, 11:59 pm.

Info about data: You are interested in how bacteria grow under different conditions. You put the bacteria *E. coli* on growth media with two types of sugars, glucose and another sugar, and observe the following growth patterns. The x-axis represents time in hours, and the y-axis is an arbitrary unit of growth.



Appendix 2. Survey Questions

This survey is asking questions about the lab projects and associated reports you've done in BIMM101. No individual identifying information will be attached to your survey responses. Your time and input are very valuable - thank you!

1. How would you define ownership over a research project?

2. Please rank the ownership you feel you had over these projects, from most at the top to least at the bottom.
    A. Agarose gel electrophoresis to analyze two DNA samples
    B. PCR variations
    C. Ligation/transformation efficiency
    D. Site directed mutagenesis

Please answer the next few questions about the project you felt like you have the ***most*** ownership over.
What project is this: _____

* Half of the course sections did most and half the least. *

3. At the time of writing a report on this project, I thoroughly understood the molecular biology topics related to this project.
    a. Strongly Agree
    b. Agree
    c. Undecided
    d. Disagree
    e. Strongly Disagree

4. Consider your role as an author of the report for this project. How much do you agree or disagree with these statements?

    1) I understood my ethical responsibilities as an author to accurately represent the research and methodological design (in the Introduction & Methods sections).
        a) Strongly Agree
        b) Agree
        c) Undecided
        d) Disagree
        e) Strongly Disagree

    2) I understood my ethical responsibilities as an author to report honest and valid data (in the Results section).
        a) Strongly Agree
        b) Agree
        c) Undecided
        d) Disagree
        e) Strongly Disagree

3) I understood my ethical responsibilities as an author to properly acknowledge other sources.
    a) Strongly Agree
    b) Agree
    c) Undecided
    d) Disagree
    e) Strongly Disagree

5. How did you come up with your hypothesis and predictions for this report?

6. Which approach below best matches what you did when writing the Introduction section for this lab project?
    A. Reviewed background information, then arranged them together in the Introduction.
    B. Wrote the Introduction from my own understanding, then found sources to support what I wrote.
    C. Other, please describe: _____

7. Which sources of information did you rely on the most when writing the Introduction? Please rank them from relied on the most to the least.
    A. Lab Manual
    B. Class slides/notes
    C. Primary literature
    D. Online sources

8. When writing the Methods section, I first made sure I fully understand the whole procedure and then proceeded with writing.
    A. Strongly Agree
    B. Agree
    C. Undecided
    D. Disagree
    E. Strongly Disagree

9. Which approach below best matches what you did when writing the Methods section for this lab project?
    A. I summarized the lab procedures on my own and looked back into the manual for specific details like the names or concentrations of reagents.
    B. I read through the lab manual while writing and summarized the procedures step by step.
    C. Other, please describe: _____

10. How did you decide which data to analyze and compare for this report?

11. What sources of information do you use to help write the Discussion section of your report?

12. If you had to write about “future directions” in you report, how did you come up with the future directions of the project?

13. The lecture slides and/or lab manual alone provided me with adequate materials to write my lab report.
    A. Strongly Agree
    B. Agree
    C. Undecided
    D. Disagree
    E. Strongly Disagree

14. Now, consider the project you felt you had the *most* ownership over and compare that to the project you felt you had the *least* ownership over. Do you think your sense of project ownership influences how you write your report? Please explain how and why or why not.

Appendix 3. Rubric used for coding student responses to Free Response Question, "How did you come up with your hypothesis and predictions for this report?"

Q5. How did you come up with your hypothesis and predictions for this report?		
Category 1	Direct use of ready-made info	Repeat the hypothesis or predictions made in class, on lab manual, etc.
Category 2	Reasoning from scientific facts learned in this class	Educated predictions based on lecture materials and/or lab manual; apply what learned in class into the Intro
Category 3	Incorporating knowledge outside this class	Using knowledge from previous courses, papers, online sources, etc.
Category 4	Arbitrary guessing	Hypothesis/predictions not based on any knowledge; random picking
Category 5	Discussion	Discuss with peers, TAs, profs, etc.

Appendix 4. Rubric used for coding student responses to Free Response Question, "How did you decide which data to analyze and compare for this report?"

Q10. How did you decide which data to analyze and compare for this report?		
Category 1	Data relevant to the purpose of the lab	Related to the main goal, but didn't say if support hypothesis or not, can be either; or only the data that support the hypothesis
Category 2	Valid data	Accurate measures; no mistakes made during the procedure
Category 3	Instructed	Guidelines, instructions from prof., TAs, lecture, lab manual, etc.
Category 4	Discussion and collaboration	Discuss with peers, prof and TAs; compare results from other groups
Category 5	Based on stats knowledge	Eliminate outliers; data that reveal statistically significant results

Appendix 5. Rubric used for coding student responses to Free Response Question 11, "What sources of information do you use to help write the Discussion section of your report?"

Q11. What sources of information do you use to help write the Discussion section of your report?		
Category 1	Sources from this class	Class slides, lab manual, notes, etc.
Category 2	Outside sources	Journal articles, primary literature, online sources, papers (including those provided by Profs)
Category 3	Previous knowledge on molecular biology	Content learned from previous classes
Category 4	Results and data	Discuss with peers, prof and TAs; compare results from other groups
Category 5	Discussion	Discuss with peers, TAs, Profs
Category 6	Rubric	Report guidelines and grading rubric

Appendix 6. Rubric used for coding student responses to Free Response Question 12, "If you had to write about "future directions" in your report, how did you come up with the future directions of the project?"

Q12. If you had to write about "future directions" in your report, how did you come up with the future directions of the project?		
Category 1	Logical next steps based on research discovery and conclusions	Research focus that extends from this project; related topics that they are interested in; other variables to change in experimental design, etc.
Category 2	Troubleshooting	Error analysis; talk about problems in procedure and errors in the collected data; discuss possible improvements to avoid errors
Category 3	Limitations	If the project is successful enough; find limitations of the project and suggest improvements

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