Understanding the Current Literature on Student Lead Experimental Design in Introductory Biology Labs

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Introduction:

This paper will address the current literature regarding the topic of student lead experimental design in undergraduate biology labs. To understand the importance of this research, we can look at this quote from Killpack, 2020: “when students perceive that they are capable of doing science, they are more likely to develop a sense that they are becoming scientists,” (Killpack, 2020). In other words, allowing students to develop their own scientific identity will assist them in developing into scientists outside of the undergraduate laboratories. This idea that scientific identity plays a helping role in students pursuing science outside of the undergraduate classroom has been supported in other studies as well (Healey, 2010). Much of the current primary research on student lead experimental design focuses on the outcome of developing students’ scientific skills, and in tandem, their scientific identity through student lead experimental design, as well as “inquiry” (which includes student lead experimental design). As stated above, when students develop a level of scientific identity, they are more likely to pursue science following their undergraduate scientific courses.

The ultimate goal of this paper is thus to understand the current research, including current proposed changes or implementations of undergraduate biology lab courses with the goal of incorporating student lead experimental design. Despite the fact that this field is newly developing, with a current shift towards more student active laboratory environments (Sundburg, Armstrong, et. al, 2005), the research is currently lacking in terms of quality, quantity, and explanatory power, all of which will be discussed in detail throughout this paper.

Methods:

To find the text used for this literature review, the following search terms were used on google scholar: experimental design introductory laboratory, introductory biology laboratory course, undergraduate biology laboratory experiment design, student experiment design, undergraduate biology lab, undergraduate biology laboratory student lead experimentation, and open ended experimental design introductory biology labs. Using these search terms, 23 papers were chosen to both represent the current research on student led experimental design in introductory biology labs, as well as some of the current research on student led experimental design in other STEM related introductory lab courses. These papers were then summarized in the form of an annotated bibliography used to assist in the writing of this paper.

Understanding the Current Research:

Inquiry:

To be able to understand the current research produced regarding student lead experimental design, firstly we have to understand the terms and definitions that will be used throughout the rest of this paper. It is important to note that throughout the current literature, there are discrepancies and differences between the definitions used for common terms - as well as many papers failing to define terms at all. One common terms used throughout all of the literature yet not defined within the papers is the word "inquiry". To be able to continue throughout this paper we must make sense of this. In an article written by Lisa Marten-Hansen, inquiry falls into four primary categories: open inquiry, guided inquiry, coupled inquiry, and structured inquiry (Marten-Hansesn, 2002). Even with these four overarching "types" of inquiry, many of the articles still didn't indicate a "type" of inquiry, and they also didn't define what they meant as inquiry within their article.

Outcomes of Inquiry:

A study done in 2019 on the effects of guided inquiry within Biology labs on experimental design skills showed that even though guided inquiry did not necessarily cause an overall change in students' experimental design skills, it did lead to an improvement in the experimental design skills of less prepared students, (Blumer, Beck, 2019). This finding contradicted a handful of the other literature within this literature review, which found that inquiry based labs lead to an overall increase in student's scientific identity, experimental ability, and self awareness of scientific ability (Killpack, 2020), (Goldstein, 2011). The actual curricular approach of the lab used in Blumer and Beck's study, however, was not described to any extent beyond "guided-inquiry", yet again reflecting this aforementioned issue of a lack of definitions and descriptions within the current literature.

A consistent example across much of the literature is understanding what "student lead experimental design may entail" - reflected in the ambiguity of the phrase itself in searching for articles for this literature review. The aspects of experimental design, as well to the extent of which the students were allowed to "choose" or lead their own experiment, varied throughout the literature as well. For the purpose of this paper, the aspects of experimental design that were analyzed in the literature includes the following: observations, question development, hypothesis development, model development, experimental procedure development, data collection, data analysis, and control creation. These differences varied primarily based on the type of research each article presented. Myers, 2003 and Goldstein, 2011 focused primarily on developing and editing pre-existing biological laboratory curriculum to allow students to better practice data analysis, whereas Blumer, 2019 studied the effects of guided-inquiry with students developing experiments based on a given question.

Based on the work from Myers, Goldstein and Blumer, the concept of student lead experimental design is any aspect of an experiment (mentioned above) that will be considered chosen by students. To best summarize what aspect of "Student lead experimental design" each article referred to, **Table 1** was created.

	Observation	Question	Hypothesis	Modeling	Experimental Procedure	Data Collection	Data Analysis	Controls
https://www.lifescied.org/doi/full/10.1187/cbe.18-06-0090	Student Chosen	Student Chosen - Limited By Materials	Student Chosen	Student Chosen	Student Chosen - Limited By Materials	Not Discussed		Not Discussed
https://www.jstor.org/stable/43631798	Student Chosen - Limited By Model	Student Chosen - Limited By Model	Student Chosen - Limited By Model	Given To Students	Student Chosen - Limited By Hypothesis/Model	Student Chosen		Not Discussed
https://search.proquest.com/docview/200326315?pq-origsite=gscholar&fromopenview=true	Given to Students	Given to Students	Student Chosen - Limited by Question	Not Discussed	Student Chosen - Limited by Question and Materials	Student Chosen - Limited by Question and Materials	Not Discussed	Not Discussed
http://www.dartmouth.edu/~mpayres/pubs/Schamel&Ayres_JCST_1992.pdf	Student Chosen / Given to Students	Student Chosen / Given to Students	Student Chosen	Not Discussed	Student Chosen	Not Discussed		Not Discussed
https://online.ucpress.edu/abt/article/73/8/454/18343/Integrating-Active-Learning-amp-Quantitative	Not Discussed	Given to Students	Not Discussed	Not Discussed	Not Discussed	Given to Students	Student Chosen - Limited by Data Collected	Not Discussed
https://www.lifescied.org/doi/full/10.11	Given to Students	Student Chosen - Limited by	Student Chosen	Not Discussed	Given to Students	Given to students	Not Discussed	Not Discussed

87/cbe.10-07-0085		Observation						
https://www.lifescied.org/doi/full/10.1187/cbe.13-11-0218	Not applicable - index creation to test student learning.	Not applicable - index creation to test student learning.	Discussed - index creation to test student learning.	Not applicable - index creation to test student learning.	Not applicable - index creation to test student learning.	Not applicable - index creation to test student learning.	Discussed - index creation to test student learning.	Discussed - index creation to test student learning.
https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7386323/	Not Discussed	Student Chosen - Not described to what extent	Student Chosen - Not described to what extent	Not Discussed	Student Chosen - Not described to what extent	Not Discussed	Student Chosen - Not described to what extent	Not Discussed
https://journals.aps.org/prper/pdf/10.1103/PhysRevSTPER.3.020106	Given to Students	Given to Students	Student Chosen - Not described to what extent	Not Discussed	Student Chosen	Student Chosen	Student Chosen - Not described to what extent	Not Discussed
https://journals.physiology.org/doi/full/10.1152/advan.00028.2002	Given to Students	Given to Students	Student Chosen - Not described to what extent	Not Discussed	Student Chosen	Student Chosen	Student Chosen - Not described to what extent	Student Chosen - Not described to what extent

Table 1: This table summarizes what aspects of student lead experimental design were mentioned within the articles and to what extent. This table does not include an exhaustive list of all of the articles used within this paper, but instead all of the articles that include reference to student lead experimental design.

One of the important things to note for this paper, as can be seen through looking at the table alone, that there is a wide discrepancy in what is actually discussed throughout the present literature. Table 1 reflects the aspects of experimental design students were allowed to choose, as well as to what extent they chose. The information presented in the table demonstrates a huge disparity throughout each aspect of experimental design and how much of it students were able to choose. To be able to accurately understand the current literature and what it says about student lead experimental design, we must address the fact that there is an overall lack of detailed literature regarding the topic. The table shows 8 aspects of experimental design: observation, question development, hypothesis development, modeling, experimental procedure, data collection, data analysis and control development. Out of the 10 papers 3 allowed students to chose their observation, 5 allowed students to chose their question, 8 allowed students to chose their hypothesis, 1 allowed students to create models, 6 allowed students to develop their own procedure, 4 allowed students to chose how to collect their data, 5 allowed students to choose their own way of analyzing data, and 1 allowed students to choose their own controls.

Even though there is a lack of current literature regarding student lead experimental design in the biological field, we can examine the proposed curriculum changes that have been enacted. A 2005 survey study found that one of the greatest changes across the decade preceding the survey was a shift towards “student-active” environments (Sundburg, Armstrong, et. al, 2005), with an apparent 50% of liberal arts universities at the time reporting using open investigation within their introductory courses.

The publications present on student lead experimental design include both research based and papers in which only explanations on changes made at specific institutions were provided without studying their outcomes/impacts. Additionally, some studies presented both an explanation of the curriculum and student outcomes associated with curriculum changes. A study done at Brandeis University in 2011 reported on the implementation a change in the biology lab to incorporate aspects of experimental design and understanding that faculty at the institution deemed important. To implement these changes the Biology department created a semester long site directed mutagenesis experiment on a protein within the human eye lens. Each week, a particular procedure was introduced to allow the students to test an overarching hypothesis of which amino acids the students had predicted were most important in the stabilization of the human eye lens. Within this study, the main aspect of student lead experimental design was hypothesis generation, ultimately resulting in only 53% of the class understanding the concept that the lab designer's were trying to get across (Treacy, 2017). This article in particular reflects the struggles and implications of the modern research on student lead experimental design. Despite having good intentions, such as trying to develop a lab course that allowed students to be more in control of a project based experimental class rather than a modular based class, implementing a student lead experimental course without achieving the positive outcomes such as student understanding, does not imply positive changes or development.

Suggestions from Other Labs:

Beyond the scope of the biological field, research has been done in other subject areas regarding student lead experimental design, specifically physics and engineering. A 2005 study investigated a physics lab in Rutgers University that implemented a comparison based study, in which one group of students underwent a regular physics lab, with the procedure given to them, and the other group had to create their own experiments nearly in full (Etkina, Murphy, 2005). Students within the second group were given a rubric to allow the students to have an understanding of what was expected of them within their reports and experiments, as well as a problem that was meant to be solved. Unlike the aforementioned studies within the biological fields, this study implemented, presumably, more student choices within experimental design, although the article did not describe to what extent.

In another study carried out within a physics lab in 2007, a similar study was conducted, this one using the Investigative Science Learning Environment (ISLE) curriculum, (Karelina, Etkina, 2007). To compare the control group to the ISLE group, the study created a handful of “codes: that were compared between the two styles of laboratory courses: making sense, writing, procedure, TA help, off task. In comparison to the control group, the ISLE curriculum styled labs saw a positive change within each category.

Having noted the positive experiences seen throughout the physics labs, it should be noted that biology labs (as well as other STEM based courses) could use this knowledge to further the development of biology labs. Although the content of each STEM course is different, and will continue to be, the actual strategies, approaches, goals and outcomes can all be interpreted or changed to better fit biology labs.

Limitations to Changes:

Although the above research has provided a solid foundation for the future of research and development regarding the benefits of student lead experimental design in introductory biology lab courses, there are a fair amount of limitations that have hindered both the current research and implementation of the findings within the current research on the topic. One of the common issues foreseen within implementing the changes discussed above and below within this paper is the training of instructors (as well as students) to prepare themselves for teaching a new style of laboratory (Hester, 2018).

Within a survey sent out to 279 schools in 2017, it was found that limitations to implementing a change in biological labs towards an authentic research style of lab (primarily focusing on experimental design, data collection, and data analysis) were different across the types of institutions (Spell, 2017). For example, class sizes were shown to be a major barrier to 2-year institutions, research based institutions, and public institutions, however this was not a barrier to minority serving institutions. These differences across the institution types may be a reason behind the lack of detailed research on how to implement student-led experimental design aspects or inquiry within biology labs. There was, however, one primary limitation in the lack of implementing this style of lab across all types of institutions: "lack of time for faculty to develop new research experiences".

One of the common themes presented in the current research regarding student choice in experimental design within undergraduate biology labs was the fact that the courses created had to be open enough to allow for student choice, but guided enough to allow for instructors to be knowledgeable on the content being taught (Hester, 2018). This may be one of the reasons that within table 1, many of the aspects of experimental design that were considered "student chosen" were limited to the aspects of the course present. This aspect of course design alone may be one of the struggles and challenges that lead to a lack of implementation of both guided inquiry based courses and student lead experimental design within lab courses.

Proposed Changes:

One of the primary issues with simply listing off changes that should be implemented to lend itself to better student led experimental design, and thus scientific identity development, and better student understanding of experiments is as follows: changes made must be specific to each institution and institution type. However, having said that, each institution can look and try to implement either entire courses (Hester, 2018) (Kloser, 2013), or aspects from these courses that resulted in positive student outcomes. Examples may include implementing modeling into the biology lab setting (Hester, 2018) or mixing the classroom environment with research environments relating to the instructor's current research (Kloser, 2013). Ultimately the idea of "guided-inquiry" was one of the most consistent topics throughout the current literature. As stated above, this is problematic as much of the current research uses that term, without describing what they meant by it or how they actually implemented it in a lab setting.

Conclusions:

As this paper demonstrates, one thing that is clear is that we have an overall lack of information on the topic of student lead experimental design. The current research that is present is also rarely consistent, not in terms of the findings, as described above, as well as in terms of what aspects of the experimental design is actually focused on or studied. Despite the fact that there have been positive outcomes for the studies that induced experimental design led by students as well as guided inquiry, there is an unfortunate lack of definitions, explanations and fully developed research. Ultimately one of the main conclusions that we can draw from the current research is that student lead experimental design and guided inquiry could produce positive results regarding scientific identity, and experimental design understanding - however with the lack of description regarding *how* and *what* changes need to be made and implemented, it's difficult to give substantive suggestions or possible solutions to change undergraduate biology labs. Inclusion of defined terms, changes that were made in biology laboratories in each experiments, and ways to implement them will be important for realizing the promise of these student lead experimental designs.

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