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Cost-Effective, Inquiry-guided Introductory Biomaterials Laboratory for Undergraduates

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Inquiry-guided instruction has been shown as more effective than traditional instruction. In inquiry-based instruction, students work in a self-directed manner to interpret outcomes based on investigation of their own question. Here, we describe a cost-effective, sustainable biomaterials laboratory for juniors using inquiry-guided instruction at a large public university.

The four laboratory components focused on key biomaterial topics and lasted for two-to-three weeks. During the first week, students were provided with available materials pertaining to the module and worked with group members and instructor(s) to devise and test a custom hypothesis instead of using “cookie cutter” lab manuals. In the second week, students performed experiments to test their hypotheses. During the last week, students either continued to perform data collection or complete analysis appropriate for their custom experimental design, depending on experimental design. Each lab was scaled to be completed in 90 minutes. This allows for multiple mini-sessions in the allotted period, resulting in smaller groups and a variety of hypotheses. Further, this course design allowed students at a large institution to have a more personal, hands-on experience. This laboratory was developed for 120 students meeting during the same three hour block. Total costs per student for the four modules were $35 per student.

A student knowledge and value survey called the Scientific Literacy and Student Value in Inquiry-guided Lab Survey (SLIGS) was created, validated, and used to assess the inquiry-guided pedagogy. The SLIGS is comprised of two portions: Part A investigating scientific literacy and Part B investigating student value of the inquiry-guided pedagogy. Both parts were assessed for validity using factor analysis and reliability using Cronbach’s alpha. Data were analyzed with Mann-Whitney U tests for non-parametric statistics.

The SLIGS had excellent internal consistency (Cronbach’s alpha >0.8). All statements factored as anticipated with three exceptions. These exceptions will be revised and re-piloted. The scientific literacy portion showed high levels of confidence both pre- and post-intervention (76% and 91% respectively, n_{pre} = 155 and n_{post}=165). Further, there was a statistically significant increase in confidence in all ten categories including explanation of scientific outcomes (79% to 94%), assessment of experimental methodology (75% to 96%), and design of experiment (69% to 95%). With respect to the survey portion pertaining to the value of inquiry-guided labs, students showed a high level of interest [73% mid-semester (M); n_{pre} = 129 and 78% at the end of semester (E); n_{post}=162]. Further, they felt that the labs were of utility value (77%-M and 85%-E), and did not require too much in terms of emotional costs (71%-M and 69%-E). Lastly, there was a statistically significant improvement in mid- to end-of- semester assessments in several categories, including facilitation of understanding of own learning, inquiry-guided format’s contribution to success in laboratory, ability to see relevance to the real-world, and the desire to see other inquiry-guided labs.

In summary, this laboratory is not only sustainable due to low cost and time requirements but also adopts the evidence-based practice of inquiry-based instruction. Moreover, assessment showed student improvement in scientific literacy and favorable student attitudes in terms of interest (attainment value), usefulness (utility value), and emotional costs.

Introduction

Traditional laboratory courses employ standard "cookbook" exercises that limit student's training in critical thinking or analytical skills. Alternative methods of instilling critical thinking in laboratory courses include guided-inquiry exercises where students are prompted to explore specific objectives through experimentation rather than being directed what steps/experiments to conduct. The learning then shifts from an instructor-centric paradigm to a student-centric paradigm. Guided-inquiry instruction has been successfully implemented in biology, chemistry and physics courses[1–3], but has not been adapted as extensively to engineering curricula despite the inherent parallelisms to engineering design.

The study of biomaterials requires knowledge of both fundamental material science and cellular biology/physiology, particularly that pertaining to inflammation and the immune response. This required, junior-level biomaterials laboratory course integrates lecture topics with experimental design, data collection and interpretation, and scientific presentation and expands on concepts from other required courses such as biology, chemistry, and physics. The four laboratory components focus on 1) the structure and function of poly (methyl methacrylate) commonly used as bone cement, 2) the structure and function of alginate hydrogels commonly used for drug delivery, 3) metal toxicity using brine shrimp as model system with applications to medical device toxicity, and 4) cell adhesion with respect to different surfaces to explore *in vivo* reactions to biomaterials. Each of the four individual lab components lasted for two to three weeks. During the first week, a brief introductory lecture (~10-15min) and accompanying handout provides the students background knowledge of the session topic and context for the real world application(s). Moreover, the handout includes a list of available materials pertaining to the lab component. Students then work with group members and the instructor to devise and test a custom hypothesis instead of using "cookie cutter" laboratory manuals. The students work in groups of five to identify a scientific question and a testable hypothesis with the supplied materials. Each proposed question/hypothesis is then discussed as a class where the students then collectively decide on an overall question/hypothesis to pursue. By pursing one hypothesis as a class, ample data is collected, allowing for statistical analysis with appropriate sample sizes. In the second week, students perform experiments to test their hypotheses. During the last week of the module, students complete experimentation if necessary and perform statistical analysis appropriate for their custom experimental design. Each lab has been scaled so that each section of approximately 60 students (120 students total) may complete it in 90 minutes. This allows for multiple mini-sessions in the allotted lab period, resulting in smaller groups and a variety of different hypotheses to be tested. Further, this course design allowed students at large institutions to have a more personal, hands-on experience. This laboratory was developed for 120 students meeting during the same three hour block.

Here, we describe experimental materials provided for the four laboratory components. For the first laboratory focusing on the structure and function of poly (methyl methacrylate) commonly used as bone cement, available reagents included methyl methacrylate polymer with an initiator, methyl methacrylate monomer with an initiator, a variety of additives including salts, metals, wires to change biomaterial properties as well as silicone molds to make the test samples, and weights and clamps for an inexpensive deflection test. (All materials are available from Fisher.) The second laboratory about swelling properties of hydrogels provided students with alginate solutions of different concentrations (RPI), different salt solutions for physically crosslinking of the alginate (Carolina Biological Supply), and different swelling solutions (varying pHs and tonicities) for testing the hydrogels ability to swell depending on experimental modifications. Scintillation vials and scales were also provided so that students were able to calculate the swelling ratio. The third lab investigating metal toxicity included brine shrimp (Carolina Biological Supply) and different forms and types of metals (including Cobalt chloride, Nickel chloride, Cobalt and Nickel particles, as well as stainless steel and Titanium spheres available from Sigma and McMaster-Carr). The final lab component exploring cell adhesion on different substrates commonly used in biomaterials and biological research included the following reagents: fibroblasts (kindly donated), glass coverslips, culture materials (RPI, BioWorld, Sarstedt), poly L-lysine (Fisher), and gelatin (Sigma). In this lab, students may also explore hydrophobicity and hydrophilicity of different surfaces using a goniometer. To assess the inquiry-guided pedagogy described above, results from a new, validated student knowledge and value survey called the Scientific Literacy and Student Value in Inquiry-guided Lab Survey (SLIGS) were analyzed.

Methods

Validation and Reliability Assessment of Scientific Literacy and Student Value in Inquiry-guided Lab Survey (SLIGS)

A custom attitudinal survey was administered anonymously to discern scientific literacy and student value regarding an inquiry-guided laboratory midway through the semester and at the end of the semester. Statements 1-10 pertained to scientific literacy and were modified from a pre-existing survey by Lawrence Blumer (Morehouse College). Responses were scaled one to four with “1” meaning “not confident” and “4” meaning “very confident”. Statements 11-23 pertained to student value of the inquiry-guided format and statements were modified from the validated Student Value Survey on Muddiest Points (SVM) created by Carberry, et al. which focuses on interest and utility value as well as cost related to another student-centered intervention called muddiest points.[4] The scale ranges from one meaning “strongly disagree” to four meaning “strongly agree”. Please see Supplement A for the Scientific Literacy and Student Value in Inquiry-guided Lab Survey (SLIGS).

SLIGS was assessed for reliability and validity using pilot study data. Here, reliability is defined as the degree to which an assessment tool produces consistent results and validity is defined as how well a test measures what it is intended to measure. Reliability is assessed using the Cronbach’s alpha and validity is assessed using factor analyses to ensure questions measuring the same latent (hidden) variable group together.

Statistical Analysis for Scientific Literacy Portion of the SLIGS

Mann-Whitney tests for non-parametric data were used to investigate differences in rating means at the beginning and end of the semester using the entire data sets from multiple semesters (n_{mid}=155 and n_{final} =165). P-values less than 0.05 were considered significant. Percentages of those confident (selecting a rating of “3” or “4”) and those that were not confident (selecting a rating of “1” or “2”) were calculated at the beginning and end of the semester.

Statistical Analysis for Student Value of Inquiry-guided Portion of the SLIGS

Mann-Whitney tests for non-parametric data were used to investigate differences in rating means at the midway and end of the semester using the entire data sets from multiple semesters (n_{mid}=129 and n_{final} =162). P-values less than 0.05 were considered significant. Percentages of those in agreement (selecting a rating of "3" or "4") and those that were not in agreement (selecting a rating of "1" or "2") were calculated at the midway and end of the semester.

Results

Student-created Hypotheses and Cost Analysis of Inquiry-guided Biomaterials Laboratory

Total costs per student for the four modules was less than $35 per student. More specifically, each module cost less than $15, $5, $5, and $10 per student respectively. Examples of hypotheses for each of the modules are as follows: In lab module 1, students hypothesized that inclusion of salt additives would affect the Young's modulus of poly (methyl methacrylate). In lab module 2, students hypothesized that acidic swelling fluid would result in less swelling than more neutral swelling fluid using research studies linking hydrogels for drug delivery to physiological pHs. For lab module 3, students hypothesized that Cobalt particles would be result in higher levels of toxicity than Nickel particles. Finally, in lab module 4, students hypothesized that gelatin and poly L-lysine would increase cell adhesion as compared to cell adhesion on uncoated glass coverslips. Laboratory handouts, list of materials, and student value survey are available through the authors.

Validity and Reliability of SLIGS

Factor and reliability analysis demonstrated that both scientific literacy and student attitude portions of the SLIGS were reliable and valid according to a pilot study. Briefly, reliability analysis showed a Cronbach's alpha of greater than 0.8 indicating excellent internal consistency. A confirmatory factor analysis yielded coefficients greater than 0.5, except the question about graphing (0.368), indicating that the majority of the questions intended to address the same latent variable did so. More specifically, the following statements grouped together: 1) all statements pertaining to scientific literacy, except the graphing statement, 2) all statements pertaining to attainment value in the inquiry-guided laboratory, expect the statement about increasing interest (attainment value)[4], 3) all statements pertaining to usefulness (utility value)[4] in the inquiry-guided laboratory, and 4) all statements pertaining to emotional costs.

Improved Confidence in Scientific Literacy

Non-parametric analysis showed a statistically significant improvement in all scientific literacy statements. More specifically, there was a statistically significant improvement in student confidence at the beginning (n_{pre}=155) and end of the semester (n_{post}=165) with regards to 1) stating a testable hypothesis ("hypothesis", $p<0.001$), 2) explain scientific outcomes ("explanation", $p<0.001$), 3) assess methodology ("methodology", $p<0.001$), 4) understand journal articles ("articles", $p<0.009$), and 5) interpret graphs ("graphs", $p<0.001$) as seen in Figure 1 below. Further, there was a statistically significant improvement in student confidence with regards to 1) designing experiments (“design”, $p<0.001$), 2) assessing scientific literacy (“assess”, $p<0.001$), 3) relating science to society (“impact”, $p<0.02$), 4) challenging authority (“challenge”, $p<0.001$) and 5) locating scientific information (“research”, $p<0.009$) as shown in Figure 2 below.

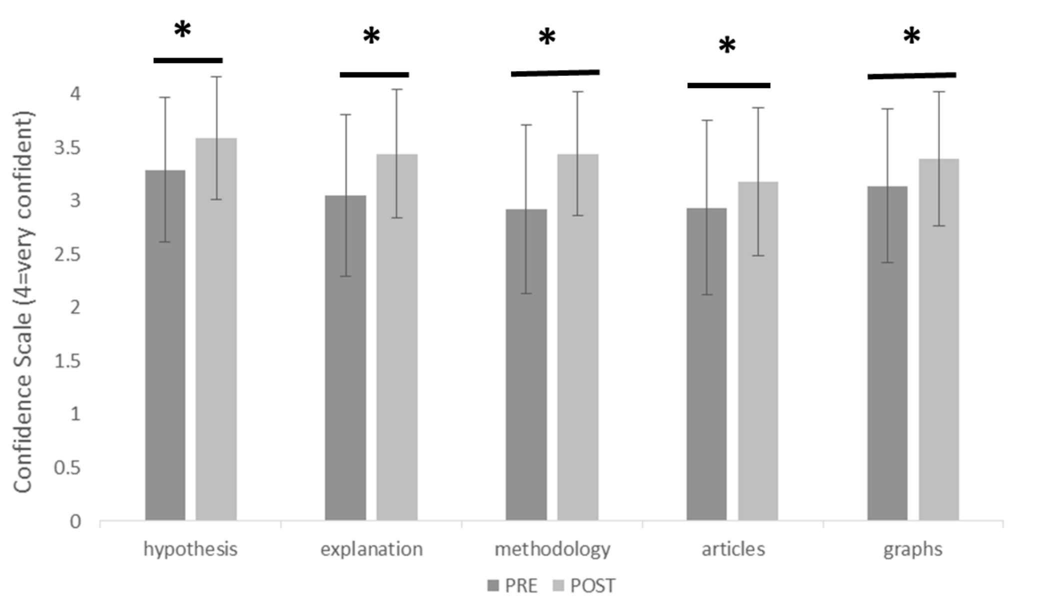

Figure 1: Student Confidence in Scientific Literacy. Non-parametric analysis shows a statistically significant improvement in student confidence regarding stating a testable hypothesis, explaining scientific outcomes, assessing methodology, reading journal articles, and interpreting graphs from the beginning to the end of the semester (* $p<0.02$; $n_{pre}=155$ and $n_{post}=165$, error bars = standard deviation).

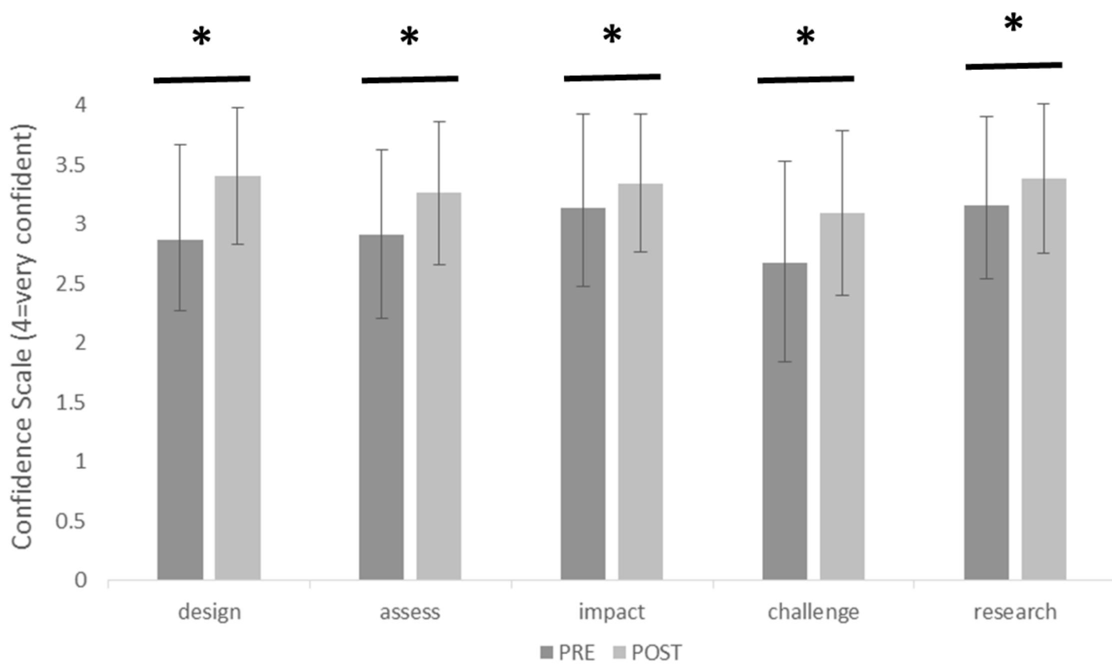

Figure 2: Student Confidence in Scientific Literacy. Non-parametric analysis shows a statistically significant improvement in student confidence with regards to designing experiments, assessing scientific literacy, relating science to society, challenging authority, and locating scientific information from the beginning to the end of the semester (* $p<0.02$; $n_{pre}=155$ and $n_{post}=165$, error bars = standard deviation).

Table 1 below shows the percentage of students that felt confident in each of the ten statements. More specifically, prior to the inquiry-guided laboratory, students were least confident in understanding journal articles (72%), designing experiments (69%), and challenging scientific authority (55%). After the inquiry-guided laboratory, the majority of the students were confident in all ten scientific literacy tasks with the lowest percent confidence being 76%. Furthermore, students were most confident in designing an experiment (95%), assessing experimental methodology (96%), and stating a testable hypothesis (97%). The largest gains in confidence were in “assessing experimental methodology” (20% increase), “challenging scientific authority” (20% increase), and “designing an experiment” (26% increase).

	Pre (n≤155)	Post (n≤165)
State testable **hypothesis**	90%	97%
Explain scientific outcomes	79%	94%
Assess experiment **methodology**	75%	96%
Understand journal **articles**	72%	86%
Interpret **graphs**	85%	93%
Design experiment	69%	95%
Assess scientific accuracy	75%	88%
Relate science to society (**impact**)	79%	92%
Challenge scientific authority	55%	76%
Locate scientific information (**research**)	85%	94%

Table 1: Summary of Percentage of Students Confident with Scientific Tasks.

Student Attitude Regarding Inquiry-guided Laboratory

As mentioned above, the latter portion of the SLIGS pertains to student attitude about the inquiry-guided laboratory. The main components of this portion include attainment value, utility value, and cost. In all categories, students agreed that the inquiry-guided pedagogy was of both attainment and utility value and did not cost too much in terms of emotion. Further, in terms of attainment value or interest, students exhibited favorable opinions with respect to the inquiry-guided laboratory's ability to motivate ("motivated"), engage ("engagement"), assist in understanding student learning ("learning"), and make students responsible for own learning ("responsibility"). Also, there was a statistically significant increase in agreement in students understanding their own learning from mid-semester to end-of-semester ($p=0.028$, $n_{mid} = 129$ and $n_{end} = 162$) as shown below in Figure 3.

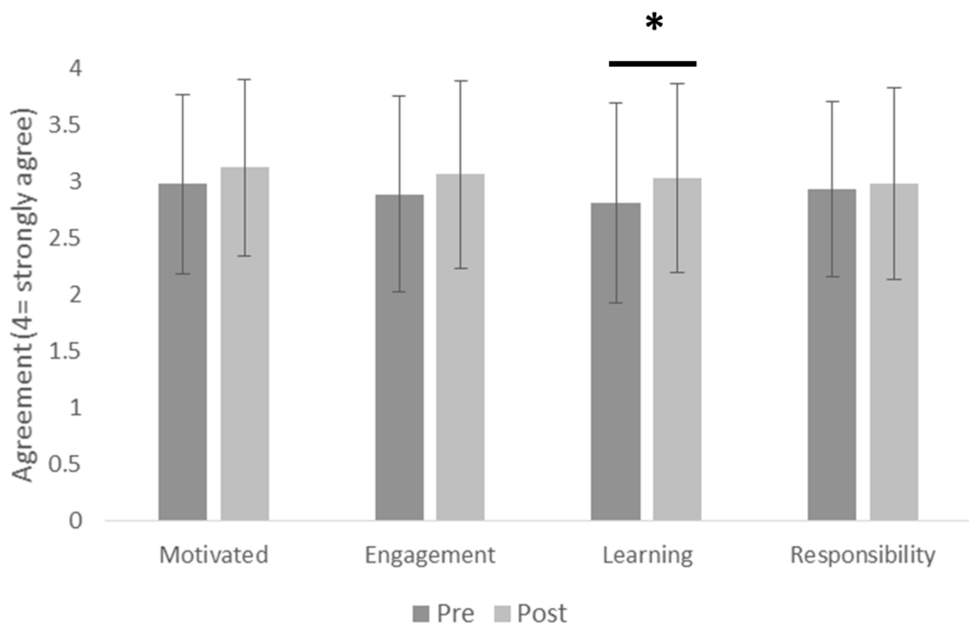

Figure 3: Student Attitudes Regarding Attainment Value or Interest. Students exhibited favorable opinions with respect to the inquiry-guided laboratory's ability to motivate, engage, assist in understanding student learning, and make students responsible for own learning. There was a statistically significant improvement in students understanding their own learning from mid-semester to end-of-semester ($p=0.028$, $n_{mid} = 129$ and $n_{end} = 162$, error bars = standard deviation).

In terms of utility value, students viewed favorably the inquiry-guided laboratory's ability to be of value after graduation ("Value"), be useful in their career or future career goals ("Career"), and help them see the relevance of the material to the real world ("RealWorld") as shown in Figure 4 below. Further, there was a small but statistically significant increase in agreement that the inquiry-guided format allowed students to see the relevance of the material to the real world ($p=0.032$, $n_{mid} = 129$ and $n_{end} = 162$).

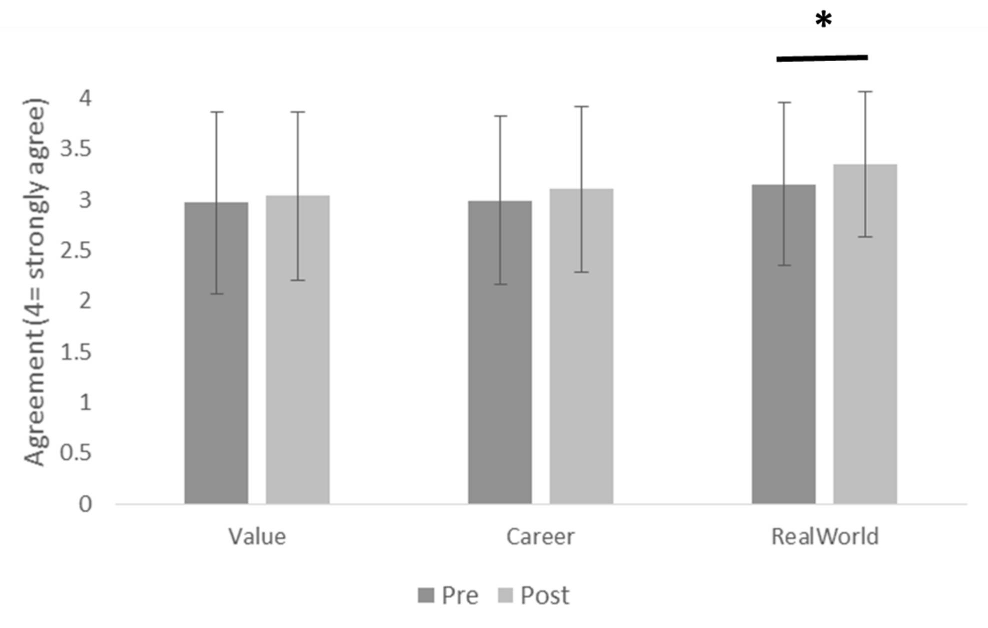

Figure 4: Student Attitudes Regarding Utility Value. Students exhibited favorable opinions with respect to the inquiry-guided laboratory's ability to be of value after graduation, be useful in their career or future career goals, and help them see the relevance of the material to the real world. There was a statistically significant improvement in the students' ability to see the relevance of the material to the real world from mid-semester to end-of-semester using the inquiry-guided format ($p=0.032$, $n_{mid} = 129$ and $n_{end} = 162$, error bars = standard deviation).

Furthermore, students did not feel that the inquiry-guided laboratory was too costly in terms of emotion as shown in Figure 5 below. More specifically, students did not feel that the pedagogy made them anxious or took too much effort. There was no change in student opinion regarding these points throughout the semester.

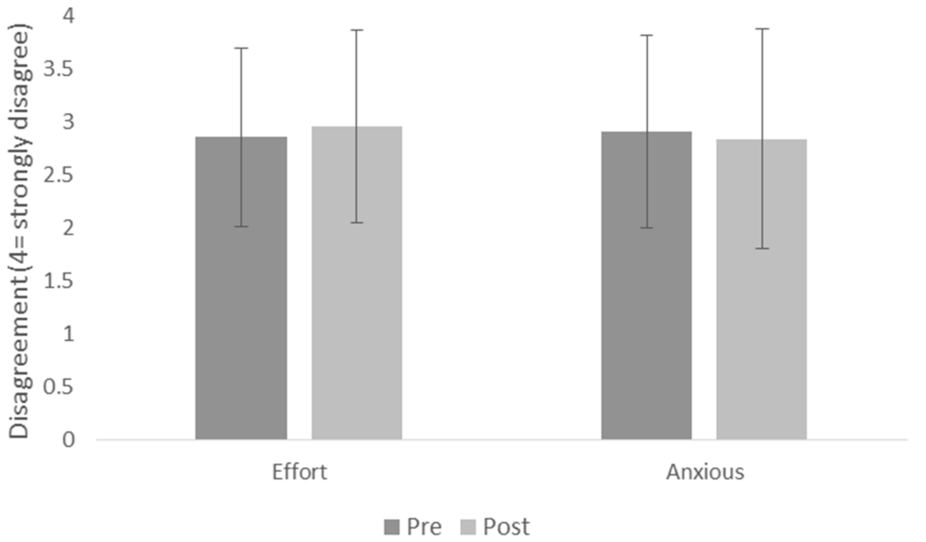

Figure 5: Student Attitudes Regarding Cost. Students disagreed that the inquiry-guided pedagogy took too much effort or make them feel anxious. This opinion did not change over the course of the semester (n_{mid} = 129 and n_{end} = 162, error bars = standard deviation).

In addition to the statements addressing expectancy/value theory (attainment value, utility value, and cost) above, four other statements were included on the student attitude portion of the SLIGS as well. As shown in Figure 6 below, students had favorable opinions about the inquiry-guided pedagogy's ability to make the student successful in the course ("Success") and increase interest in the course ("Interest"). Further, the students felt that they would like to see the format used in other laboratories ("OtherLabs") and would recommend the lab to others ("Recommend"). From the mid-point to the end-of-the-semester, there was a statistically significant increase in agreement pertaining to the inquiry-guided format and its ability to facilitate student success (p=0.021) and students' desire to see the inquiry-guided format in other laboratories (p=0.001; n_{mid} = 129 and n_{end} = 162).

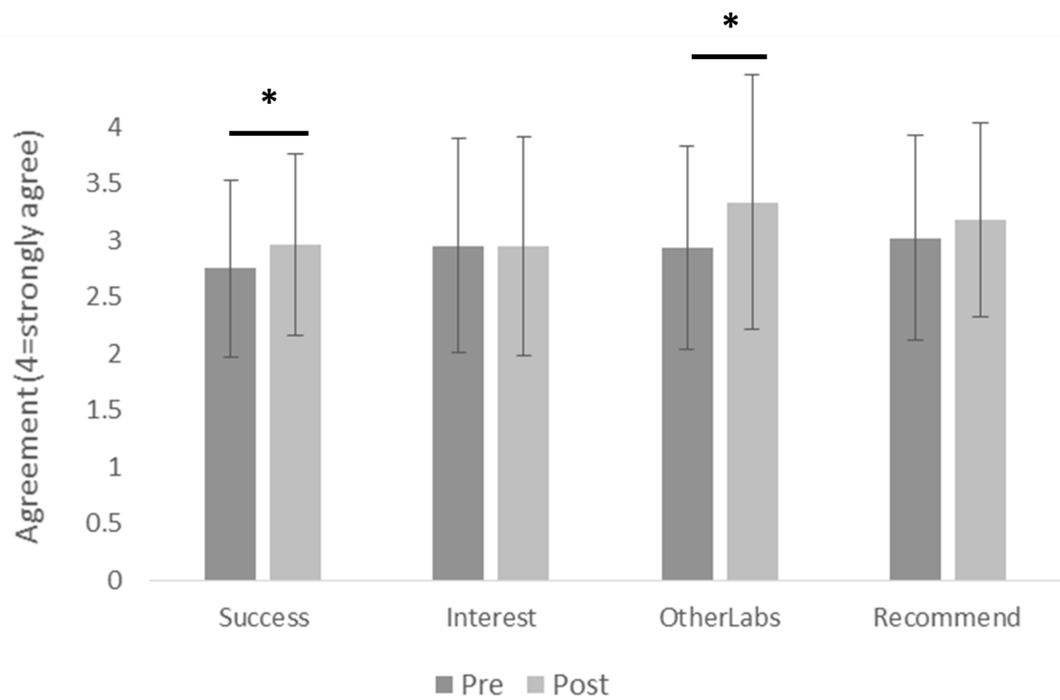

Figure 6: Student Attitudes Regarding Success, Interest, and Desire to see Format Elsewhere. Students favorably viewed the inquiry-guided format in terms of its ability to help them be successful ("Success"), increase their interest ("Interest"), and desire to be used in other labs ("OtherLabs") and recommend the lab to others ("Recommend"). There was a statistically significant improvement in the "Success" and "OtherLabs" categories (n_{mid} = 129 and n_{end} = 162, error bars = standard deviation).

Similarly to analysis described for the scientific literacy portion, percent agreement was calculated for each statement in the student attitude of inquiry-guided laboratory portion of SLIGS as shown below in Table 2. In summary, there was a high level of agreement that the inquiry-guided laboratory was of attainment value (73% mid-semester, 78% end-of-semester), utility value (77% mid-semester, 85% end-of-semester), and did not cost too much in terms of effort and anxiety (71% mid-semester and 69% end-of-semester). Moreover, the majority of students agreed that the inquiry-guided course allowed them to be successful (68% mid-semester to 75% end-of-semester) and increased their interest in the course (72% mid-semester to 69% end-of-semester). Additionally, the majority of students would like to see other labs use the inquiry-guided format (74% mid-semester to 92% end-of-semester). Lastly, the majority of the students would recommend this inquiry-guided laboratory to others (78% mid-semester to 81% end-of-semester).

	Pre	Post
Interest/Attainment Value		
motivated me to do well in course	78%	81%
was an effective why to increase engagement	75%	79%
helped me better understand my own learning	73%	77%
increased my level of responsibility	67%	76%
	73%	**78%**
Utility Value		
will be of value after graduation	74%	79%
was useful in career and/or graduate school goals	76%	83%
helped me see relevance to real world	81%	93%
	77%	**85%**
Cost		
did not required too much effort	73%	74%
did not make me frustrated and anxious	68%	63%
	71%	**69%**
Other		
helped me to be successful	68%	75%
increased interest in course	72%	69%
would like to see guided-inquiry in other labs	74%	92%
would recommend to others	78%	81%

Table 2: Summary of Student Attitude regarding the Inquiry-guided Laboratory

Discussion and Conclusion

The aforementioned work highlights the creation of a cost- and time-effective, inquiry-guided biomaterials laboratory for large numbers of students. Further, the authors have developed a valid and reliable survey to assess both scientific literacy and student value of this evidence-based, inquiry-guided laboratory format. Results show a statistically significant improvement in scientific literacy in all ten categories with the highest gains in designing experiments, challenging scientific authority, and assessing scientific methodology. Further, students favored the inquiry-guided format in terms of attainment value, utility value, and cost.

Future work will focus on creating a direct assessment method to complement the scientific literacy portion of the SLIGS. Creation of a direct assessment, such as a concept quiz or assessment of class assignments, will allow for another means to assess improvement in scientific literacy without the chance for self-reporting bias seen by others.[5] It is still important for the students to reflect on their own learning through the SLIGS. Studies have shown that reflection allows for students to practice “scaffolding” which is the process of linking current learning to previous knowledge, an important skill for all students, especially engineers.[6]

Another goal of the authors is to use the same measures (the SLIGS and direct assessment) in a traditional laboratory classroom with similar content and time frame; however, at this time, only one section of the biomaterials course is taught in the department. Comparing with another biomaterials course at a different university or another laboratory course within the same department may not yield insight as there would be many other differences in instruction other than the inquiry-guided format. Additionally, students will be surveyed about other laboratory courses that they have taken prior to this course to consider the impact of different laboratory experiences on our results. Moreover, future work will focus on investigating which particular aspects of the guided inquiry laboratory are most effective.

Interestingly, among all ten categories of the scientific literacy portion of the SLIGS, "challenging scientific authority" was the lowest at course onset. Others have seen a similar phenomenon.[7] According to Chen, students are rarely given the opportunity to challenge scientific authority through exercises such as journal critiquing. Future work will investigate this finding and explore potential explanations including gender. Also of interest is the fact that students had the second highest gain in this category in the inquiry-guided setting, suggesting that this pedagogy is an effective way to improve this aspect of scientific literacy.

With respect to student value of the inquiry-guided format, there were few changes in opinion. Namely, there was a statistically significant increase in the students' understanding of their own learning, ability to relate material to the real world, opinion that the inquiry-guided format facilitated success in the course, and the desire to see this format used in other laboratory classes. It is not surprising that each of these statistically significant increases were small because implementation of the intervention did not change from the midway and end-of-semester administration of the SLIGS. Further, analysis from both administrations showed a high opinion in all categories with each category (attainment value, utility value, and cost) averaging approximately 70% in agreement or higher.

In summary, this laboratory is not only sustainable due to low cost and time requirements but also adopts the evidence-based practice of inquiry-based instruction. Moreover, results from the custom, validated SLIGS instrument showed student improvement in scientific literacy and favorable student attitudes in terms of interest, utility, and emotional costs.

Supplement A: Scientific Literacy and Student Value in Inquiry-guided Lab Survey (SLIGS)

For Statements 1-10: 1 = not confident and 4 = very confident

1. Pose a question that can be addressed through scientific experimentation, e.g. state a testable hypothesis.
2. Provide a scientific explanation for experimental outcomes.
3. Assess the appropriateness of the methodology of an experiment.
4. Read and understand journal articles.
5. Read and interpret graphs displaying scientific information.*
6. Design an experiment that is a valid test of a hypothesis.
7. Assess the accuracy of scientific statements.
8. Relate scientific discovery or idea to the impact on society.
9. Challenge authority on evidence that supports scientific statements.
10. Locate valid scientific information when needed.

For Statements 11-23: 1=strongly disagree and 4 = strongly agree

11. The guided-inquiry format has motivated me to do well in the course.
12. The guided-inquiry format required too much effort.
13. The guided-inquiry format increased my engagement in the course.
14. The guided-inquiry format helped me better understand my own personal learning.
15. The guided-inquiry format made me frustrated or anxious.
16. The guided-inquiry format increased my responsibility for my own learning.
17. The guided-inquiry format helped me to be successful in the course.*
18. The guided-inquiry format decreased my interest in the course.*
19. The material learned in this guided-inquiry lab will be of value to me after graduation.
20. The material learned in this guided-inquiry lab will be useful in the pursuit of my career and/or educational goals.
21. This guided-inquiry lab helped me learn the importance of biomaterials to the real world.
22. I would like to see the guided-inquiry format used in other lab classes.
23. I would recommend this guided-inquiry lab to others.

*These statements did not factor as anticipated.

Works Cited

1. Lee VS. What is inquiry-guided learning? *New Dir Teach Learn*. 2012;(129):5-14.

2. Deslauriers L, Wieman C. Learning and retention of quantum concepts with different teaching methods. *Phys Rev Spec Top - Phys Educ Res*. 2011;7(1).

3. Howard CJ, Gray ME. An Investigative Case Study Designed to Promote Critical Thinking Skills. . *Test Stud Lab Teach*. 2004;25:312-315.

4. Carberry A, Waters C, Krause S, Ankeny C. "Unmuddying" Course Content Using Muddiest Point Reflections. *Front Educ*. 2013;Oct 23-26:937-942.

5. Howard GS. Response-Shift Bias: A Problem in Evaluating Interventions with Pre/Post Self-Reports. *Evalution Rev*. 1980;4:93-106.

6. Costa, Arthur L, Kallick B. *Learning and Leading with Habits of Mind*.; 2009.

7. Chen Y-C. Constructing and critiquing arguments: four communication strategies help students discuss, defend, and debunk ideas. *Sci Child*. 2013;50(5):40.