# WIP: Improving Biomedical Engineering Retention through Experiential Learning in Biocompatibility

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## Introduction

Engineering programs nationwide experience attrition rates of 40-60% [1] - [5]. The first year is a critical period during which students form their professional identities and career aspirations. Approximately 22% of students leave during their first year. This challenge is especially pronounced in the State of Maine, where the Biomedical Engineering (BME) program has experienced high attrition despite the discipline's emphasis on interdisciplinary approaches that integrate engineering principles with biological and medical applications. Establishing this foundation early is essential not only for student success but also for sustaining a qualified biotechnology workforce. Prior research suggests that attrition is often linked to traditional instructional approaches that insufficiently connect theoretical concepts and do not clearly articulate pathways between skill development and career opportunities, practical applications [2].

Experiential learning has emerged as a promising pedagogical approach for addressing both student retention and workforce preparation. Studies demonstrate that hands-on, research-based experiences can foster meaningful connections between coursework and practice, build stronger learning communities, increase engagement, and reduce attrition rates [6] - [9]. For BME students, early exposure to authentic research practices may be particularly valuable in developing professional identity, clarifying career pathways in biotechnology, and building technical competencies valued by employers.

This Work-in-Progress paper presents an ongoing educational research project that leverages experiential learning to strengthen workforce pipelines and improve student retention in BME. The project centers on a newly developed Biocompatibility Module providing first-semester students with hands-on experience in biomaterials testing, cell culture, and fundamental microscopy competencies in BME practice. This module's goals are threefold: (1) improve first-year retention when attrition risk is highest; (2) increase student awareness of diverse BME career opportunities in the growing biotechnology sector; and (3) develop skilled professionals prepared to meet regional workforce needs. Assessing the first two goals was completed by surveys based on the Pittsburgh Freshman Engineering Attitudes Survey [6], [7]. A qualitative evaluation of student assignments using the Engineering Habits of Mind framework [8], [10], [11] was used to track improvements in professional skills (University of Maine IRB # 2025-07-07).

## Methods

The biocompatibility module consisted of small lectures integrated with hands-on activities to introduce foundational concepts in tissue engineering. Instruction covered core topics including sterile/aseptic technique, cell culture, hemocytometer-based cell counting, and principles of experimental design and hypothesis testing aligned with ISO 10993 standards. Students were introduced to cellular proliferation assays, i.e., MTT assay, and performed basic statistical analysis in Excel to assess material biocompatibility. Practical activities reinforced technical skills such as pipetting and included extraction procedures in accordance with ISO 10993 guidelines to evaluate candidate biomaterial sources from students' environments. As a culminating assignment, students designed an ISO 10993-compliant experimental protocol to assess the biocompatibility of a new candidate biomaterial.

Prior to the start of the semester, the course instructor and authors identified three assignments best suited for tracking first-year students' academic growth, critical thinking, and communication throughout the semester (**Appendix A**). Each assignment required students to generate a figure from a dataset or prompt, write a descriptive statement about the figure and its results, and draw conclusions from their findings. The three assignments were strategically timed: one before the newly implemented module, one during the module, and one at the semester's end.

The Pittsburgh Freshman Engineering Attitudes Survey served as a framework for developing two surveys (**Appendix B**). Students completed surveys to track changes in their attitudes and self-confidence in their major, ranking statements from 0 - Strongly disagree, 1 - Disagree, 2 - Partially disagree, 3 - Partially agree, 4 - Agree, and 5 - Strongly agree. Surveys were administered and analyzed via Qualtrics at the beginning and end of the semester. Results were aggregated, and bar plots were generated using Excel (**Appendix C**). By the semester's end, 31 pre-module, 30 module, and 29 end-of-semester assignments were collected and de-identified for analysis, along with pre- and post-activity surveys from 28 and 24 participants, respectively.

Assignments were quantitatively evaluated by three independent reviewers using two categories from the 'Engineering Habits of Mind.' [12] Communication Skills and Critical Response Skills. Each assignment was scored on a four-point scale: 1 - below basic, 2 - basic, 3 - proficient, and 4 - advanced for both criteria independently. To standardize scoring, reviewers independently scored six randomly selected assignments and then convened to discuss their scores and justifications. Following this calibration, a consensus rubric (**Appendix D**), was developed and applied independently by all evaluators to score the remaining assessments.

Scores were aggregated in Excel by assignment and category, with mean values and standard deviation calculated for each group. Statistical significance was assessed using one-tailed Welch's T-test to compare the three possible parings for each category: Pre-module vs Module, Pre- module vs End of semester, and Module vs End of semester. A one-tailed test was selected based on the hypothesis that the module would increase student performance, and Welch's t-test accommodated the varying sample sizes across assignments. Statistical significance was defined as $p < 0.05$ (*), $p < 0.01$ (**), and $p < 0.001$ (***).

**Results and Discussion**

Responses to the common items on the modified Pittsburgh Freshman Engineering Attitudes Survey were summarized as percentage distributions and compared pre- and post-semester. Nearly all items showed an upward shift in score distributions, indicating improved student attitudes over time. The mean score for "*I know how to apply information from courses to my field of study*" increased from 3.1 to 3.6 (**Appendix C, Fig. C.3. A**), suggesting greater perceived relevance and transferability of course content. Agreement with "*I have no desire to change to another major*" increased from 3.2 to 3.8 (**Appendix C, Fig. C.4.A)**, reflecting strengthened disciplinary commitment. Furthermore, post-module-only survey items (**Appendix D**) indicate strong student support of this module as a meaningful and engaging component of the course rather than simply an additional workload burden. These observations are supported by changes in the distribution of responses, as shown in the difference bar plots (**Appendix C Fig C.3.B** and **Fig. C.4.B,** respectively). Collectively, these results suggest that the Biocompatibility module may have reinforced both applied understanding and engineering identity during the first semester.

Rubric-based evaluation of Engineering Habits of Mind in students demonstrated measurable gains in Communication and Critical Response skills. Communication scores increased from 2.0 ±0.7 (pre-module) to 2.5±0.8 (during module), and Critical Response scores increased from 2.1±0.6 (pre-module) to 2.6±0.6 (during module), improving in both categories by approximately 25%. A one-tailed Welch's t-test confirmed that these increases were statistically significant ($p = 1.5 \times 10^{-6}$ for Communication, and $p = 1.6 \times 10^{-6}$ for Critical Response, both***), supporting the conclusion that structured engagement with biocompatibility case studies and data interpretation contributed to students' development of higher-order analysis and technical communication skills. Although a slight decline (~4%) was observed in the end-of-semester assignments (2.4±0.8, and 2.5±0.6 in Communication and Critical Response skills respectively), scores remained elevated relative to baseline, and no statistically significant differences were detected between module and end-of semester assignments ($p = 0.22$ for Communication, and $p = 0.09$ for Critical Response, both n.s.), indicating stabilization rather than regression. In parallel, first-to-second-semester retention increased to 83%, exceeding the previous five-year average of 80% (historical low: 63%). Although causation cannot be inferred, this retention trend is consistent in direction with the observed improvements in student engagement, confidence, and skill development.

**Conclusion**

Based on students' survey responses and rubric-based assessments, the Biocompatibility module was well received and associated with improvements in students' attitudes toward their coursework, major, and skill development. Observable gains in Communication and Critical Response Skills suggest that intentional integration of discipline-specific, experiential content can support early development of Engineering Habits of Mind. The concurrent increase in first-year retention further underscores the potential value of such curricular enhancements.

This study is preliminary and should be interpreted in that context. The analysis is based on a single year of data and does not include a negative-control cohort (i.e., survey or assignment data from offerings without the Biocompatibility module), thereby limiting our ability to isolate the module's independent effect. While observed improvements in attitudes, skills, and retention are encouraging, they cannot be attributed solely to the module and may reflect students' broader exposure to college coursework, increased maturity, and adjustment to academic expectations. Further work will strengthen the study design by incorporating a broader range of assignments both within and outside the major to better elucidate patterns of skill development. Surveys will be implemented for longitudinal survey collection across all years of study within the Biomedical Engineering program. These efforts will support a more rigorous evaluation and facilitate the development of additional educational modules to enhance student engagement and improve alignment with biotechnology workforce development needs in the State of Maine.

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## Appendix A

Assignments used by independent reviewers scored using the Engineering Habits of Mind Rubric (**Appendix D**)

**Pre-module assignment**

<u>**Assignment 1 –**</u>

In this assignment, you and your lab partner will collect data using a commercially available, "cheap" pulse oximeter and the "gold" standard device (a medical-grade pulse oximeter) at various activity levels. Once you have collected your data, you will add your measurements to an aggregated Excel sheet that is shared with the entire class. Once all of the group members have added their data, you will be asked to sort the data and generate plots comparing the "cheap" device's measurements of heart rate and peripheral capillary oxygen saturation (SP02) to the "Gold" standard device.

Record the following information

- Note the number, make, and model of the tested device.
- Note the gold-standard/reference device or method used.
- Measure and record HR and SPO2 simultaneously, comparing your test device with your gold-standard (reference) instrument.
    - 10 measurements per student per condition (low, medium, elevated HR).

Enter your results in Excel in pairwise columns (HR gold, HR test, O2 gold, O2 test).

Identify breaks in your column data for each test subject (student).
Clean up your spreadsheet, label it with your device and team number
Upload your Excel sheet to the shared folder. Be sure to label your file with your device number.
Download all class data onto your laptop.

Complete and upload the following activity (as an Excel file) into Brightspace. This is an individual assignment; all students are expected to complete it on their own (compiled data can be shared).

You are encouraged to work alongside your group members to share ideas.

**YOU MUST EACH UPLOAD THE RESULTS INTO BRIGHTSPACE.**

<u>**Tasks**</u>

1. Aggregate all class data into a single Excel file.
2. Separate the data into 2 sheets (SpO2, HR).
3. Include all class data. Organize in some sensible way. Label each column for each data type. Data should be <u>in pairs</u> (Test device and reference device).
4. Use the "sorting function" to organize each column.
5. On a single scatter plot (for each sheet(SpO2, HR) ), compare the reference device (Gold standard - abscissa X) vs the Test device (ordinate Y). Use colors to distinguish each device. Include a 1:1 correlation line. Spend time making your graph clear and presentable.
6. In 2-3 sentences, identify which device you might recommend. Be sure to support your thoughts with trends in the observable data.

**Module Assignment**

Task overview:

As part of the MTT analysis, students were asked to construct a standard curve of absorbance versus cell count from raw data, using a line of best fit. Using their constructed curve, they were then asked to calculate the number of cells present from a set of "unknown" samples' absorbance values, one of which was outside the range of the data set used to construct the standard curve. Students were then asked to analyze both the standard curve and the calculated cell count and to present their analysis in a brief paragraph.

**Deliverables:** A labelled scatter plot, a data table with averages/standard deviations, the calculated unknown concentration(s), and a paragraph discussing the quality of the standard curve, the resulting calculations of the "unknowns" addressing any "unknown" absorption values outside the standard curve's range. The written paragraph should also suggest any actions to correct any issues with the standard curve or measurements of the "unknowns".

- Graphing Requirements:
  - Correct axis labels and title
  - A linear trendline (not a "curve" that connects points) must be fitted to the data.
  - The equation of the line (y=mx+b) and $R^2$ shown on the graph
    - **Linear Relationship:** The curve must demonstrate a strong linear relationship (ideally, $R^2$ values $\geq 0.99$) between concentrations and measured signals (e.g., absorbance).
- **Data Structure:** A minimum of 3–5 points for a reliable linear range is expected, often generated from a serial dilution.
- **Calculation:** Use the line equation to calculate the concentration of "unknown" samples based on their measured absorbance displayed in a table with a sample calculation.
- **Considerations:** Samples with absorbance values outside the linear range must be diluted and re-measured. Dilution factors must be factored into final concentration calculations.

**End of the semester Assignment**

Task Overview:

You are tasked with designing a **Ventilator WYE Connector**, a critical component in a breathing circuit that joins the inspiratory and expiratory limbs into a single pathway for the patient. This session focuses on your individual contribution before you merge ideas with your team.

Deliverables

You must submit a single-page document containing:

- **2D Technical Sketch:** A hand-drawn or CAD-generated (e.g., Autodesk Fusion 360) 2D view of your WYE connector.
- **Dimensioning:** Include critical dimensions based on international medical standards.
- **Design Rationale:** A one-paragraph justification of your design choices.
- Technical Requirements & Dimensions
- Your sketch must adhere to **ISO 5356-1 standards** to ensure compatibility with standard medical equipment. You must choose your dimensions for your sketch and justify your choices, provide references

**Appendix B**

Pre-module survey Statements. Students were asked to rank the following statement from 0 - Strongly disagree, 1 - Disagree, 2 - Partially disagree, 3 – Partially agree, 4 - Agree, and 5 - Strongly agree.

- My high school prepared me well for college.
- My high school prepared me well for my field of study.
- I know how to apply information from courses to my field of study. (ex. Biology, Chemistry, Math, and Physics)
- I have no desire to change to another major (ex., biology, English, chemistry, art, history, etc.).
- I have a good understanding of what biomedical engineers do.
- My academic work is interesting and engaging
- I prefer learning via traditional lecture-style classes.
- I prefer learning via experiential learning with hands-on lab-based activities.

Statements added to the pre-module survey to create the post-module survey

- I enjoyed this learning module.
- This lab-based activity improved my understanding of one area of biomedical Engineering
- I would like to see more lab-based, hands-on activities in my courses

## Appendix C

Bar plots of all students' responses to common statements in the pre- and post-modified Pittsburgh Freshman Engineering Attitudes Survey. Figures C.# A are bar plots showing the % of respondents who rank statements in the Pre-module and Post Module survey statements (**Appendix B**) from 0 - Strongly disagree, 1 - Disagree, 2 - Partially disagree, 3 - Partially agree, 4 - Agree, and 5 - Strongly agree. Figure C.# B shows the difference plot between Post-Module and Pre-Module percentages to highlight the shift in populations. Fig. C.9 through Fig. C.10 show bar plots of student responses to questions included only in the Post-Module survey.

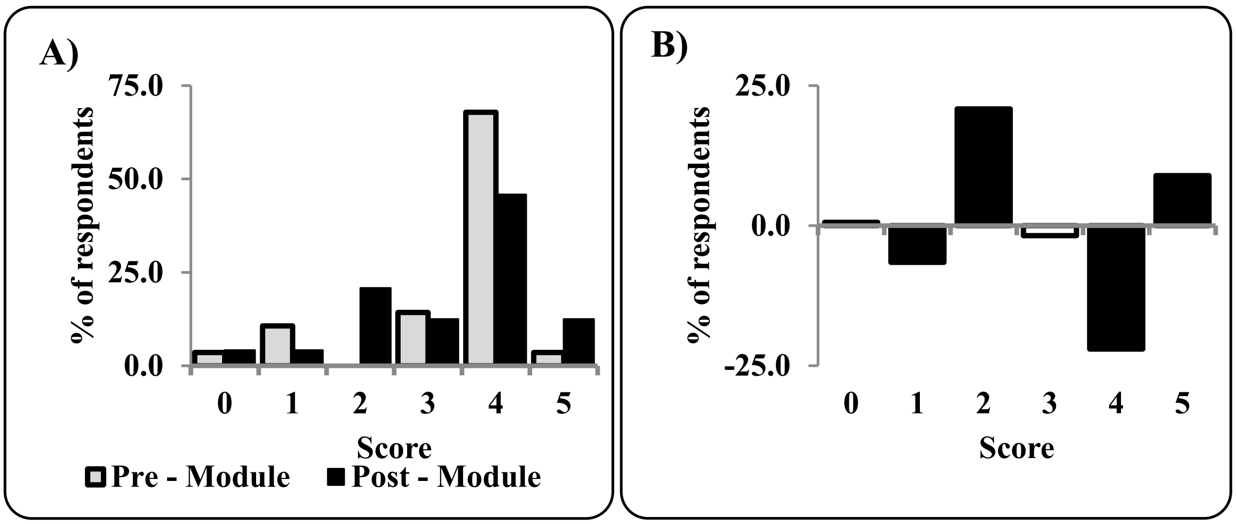


**Figure C. 1 A)** Show the bar plot of % student responses to the statement, "My high school prepared me well for college". The averages of the Pre-Module and Post-Module survey results are 3.4±1.2 and 3.3±1.3, respectively. **B)** Show the shift in the distribution of student responses.

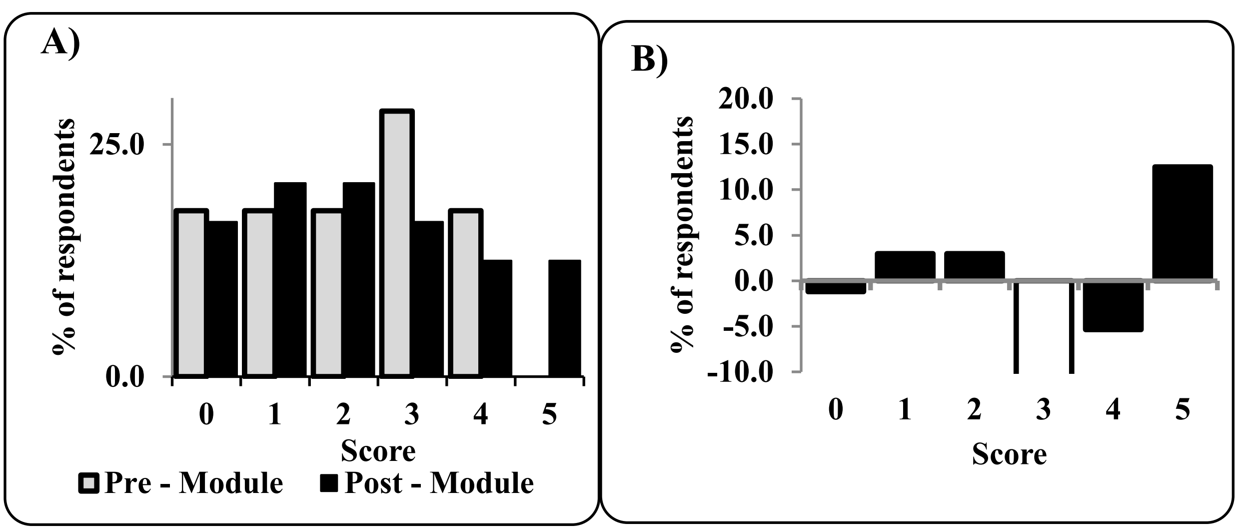


**Figure C. 2 A)** Show the bar plot of % student responses to the statement: "My high school prepared me well for my field of study". The averages of the Pre-Module and Post-

Module survey results are 2.1±1.4 and 3.29±1.3, respectively. **B)** Show the shift in the distribution of student responses.

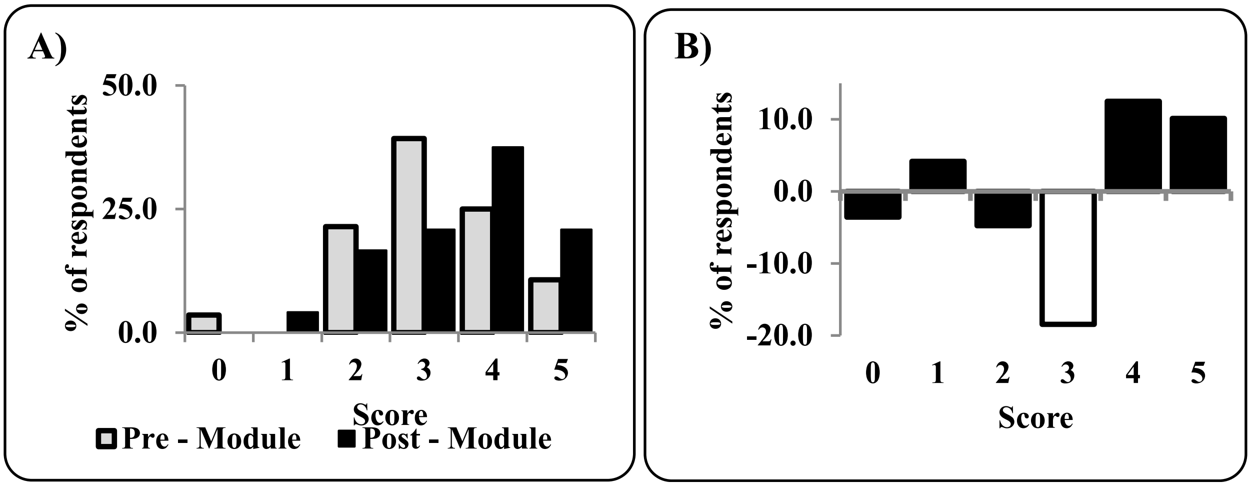


**Figure C. 3 A)** Show the bar plot of % student responses to the statement: "I know how to apply information from courses to my field of study". The averages of the Pre-Module and Post-Module survey results are 3.1±1.1 and 3.5±1.1, respectively. **B)** Show the shift in the distribution of student responses.

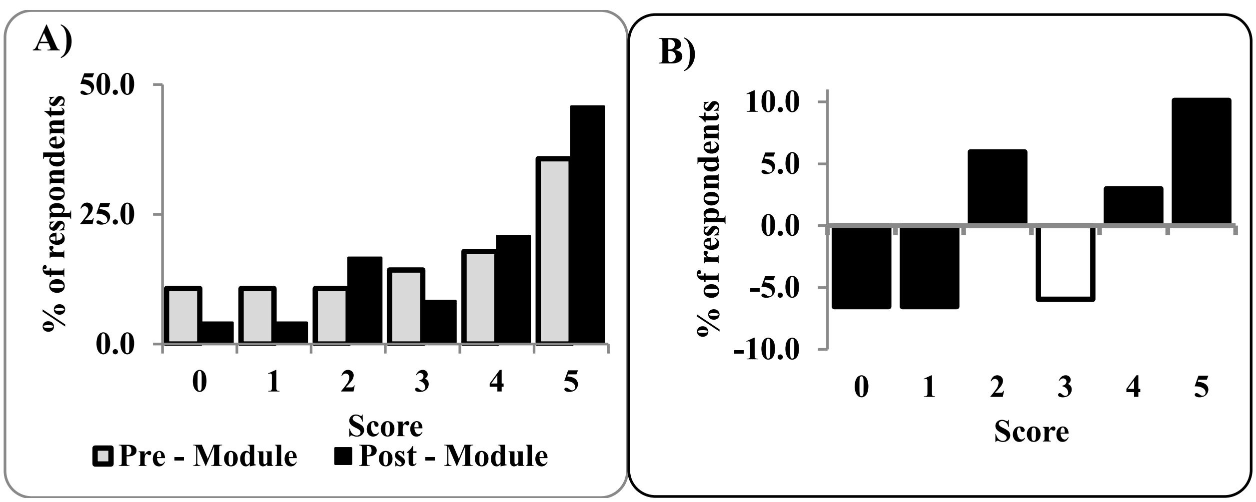


**Figure C. 4 A)** Show the bar plot of % student responses to the statement: "I have no desire to change to another major". The averages of the Pre-Module and Post-Module survey results are 3.3±1.8 and 3.8±1.5, respectively. **B)** Show the shift in the distribution of student responses.

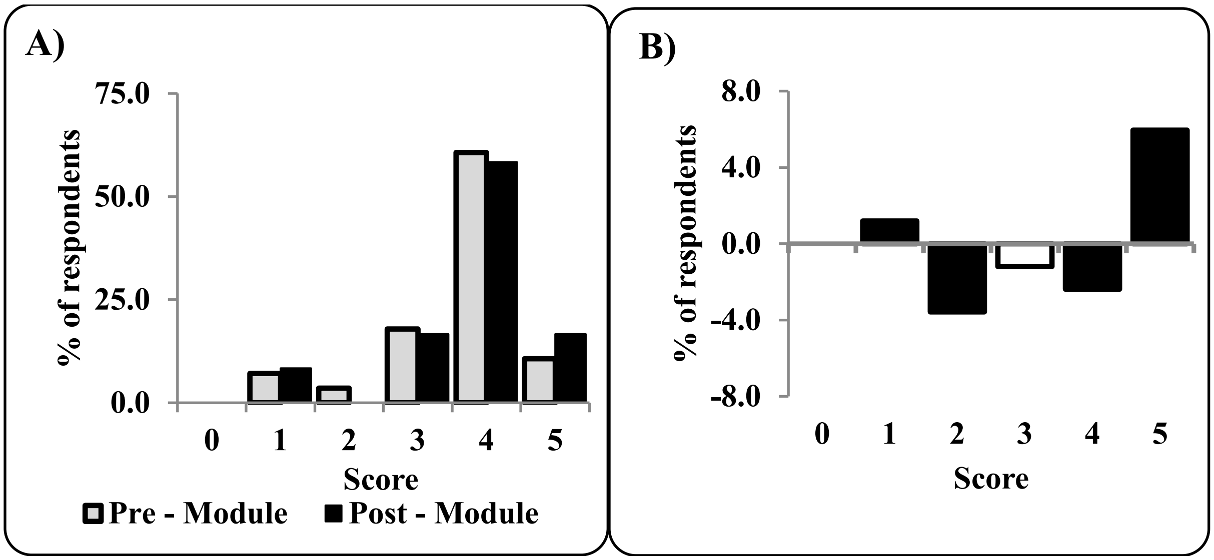


**Figure C. 5 A)** Show the bar plot of % student responses to the statement: “I have a good understanding of what biomedical engineers do”. The averages of the Pre-Module and Post-Module survey results are 3.6±1.0 and 3.8±1.0, respectively. **B)** Show the shift in the distribution of student responses

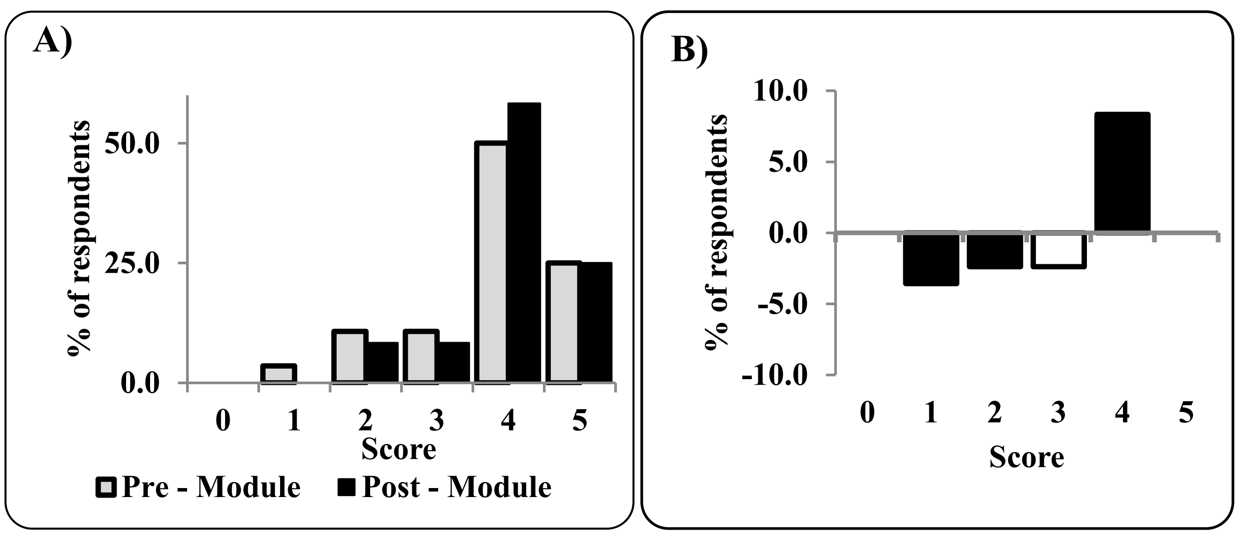


**Figure C. 6 A)** Show the bar plot of % student responses to the statement: “My academic work is interesting and engaging”. The averages of the Pre-Module and Post-Module survey results are 3.8±1.0 and 4.0±0.8, respectively. **B)** Show the shift in the distribution of student responses

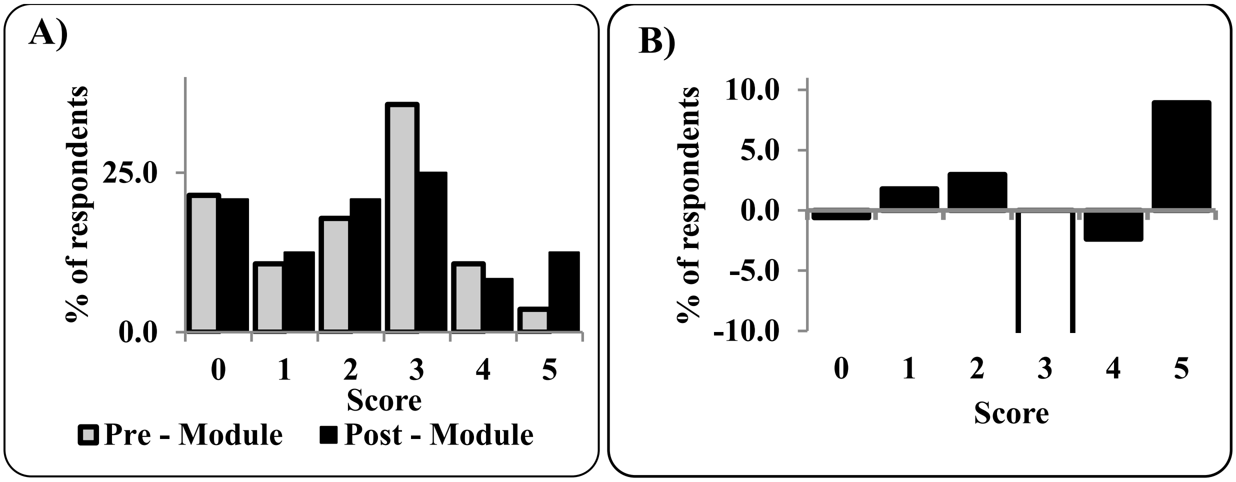


**Figure C. 7 A)** Show the bar plot of % student responses to the statement: “I prefer learning via traditional lecture-style classes”. The averages of the Pre-Module and Post-Module survey results are 2.4±1.4 and 2.3±1.6, respectively. **B)** Show the shift in the distribution of student responses

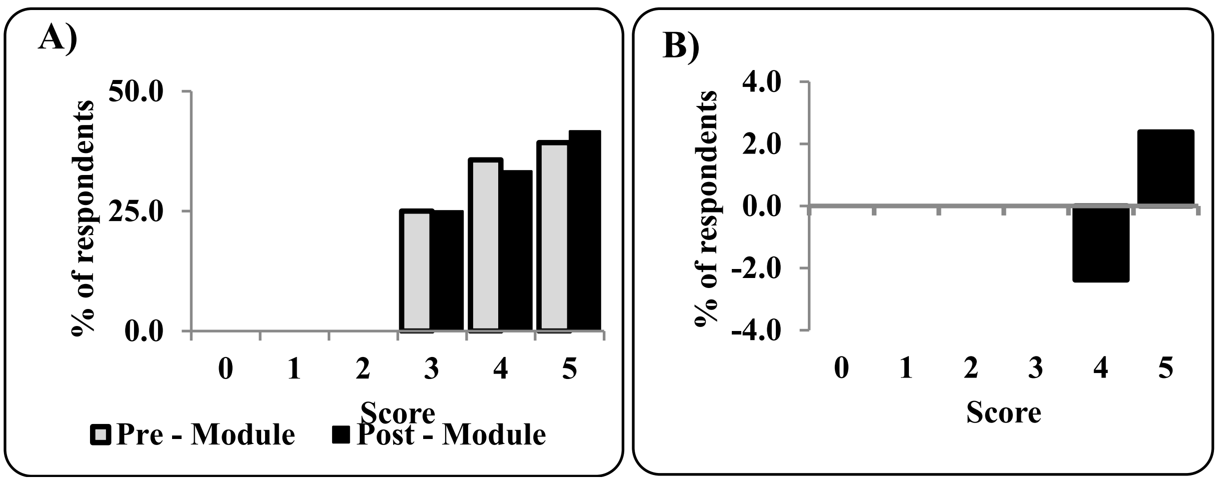


**Figure C. 8 A)** Show the bar plot of % student responses to the statement:” I prefer learning via experiential learning with hands-on lab-based activities”. The averages of the Pre-Module and Post-Module survey results are 4.1±0.8 and 4.2±0.8, respectively. **B)** Show the shift in the distribution of student responses

Responses to unique post survey questions

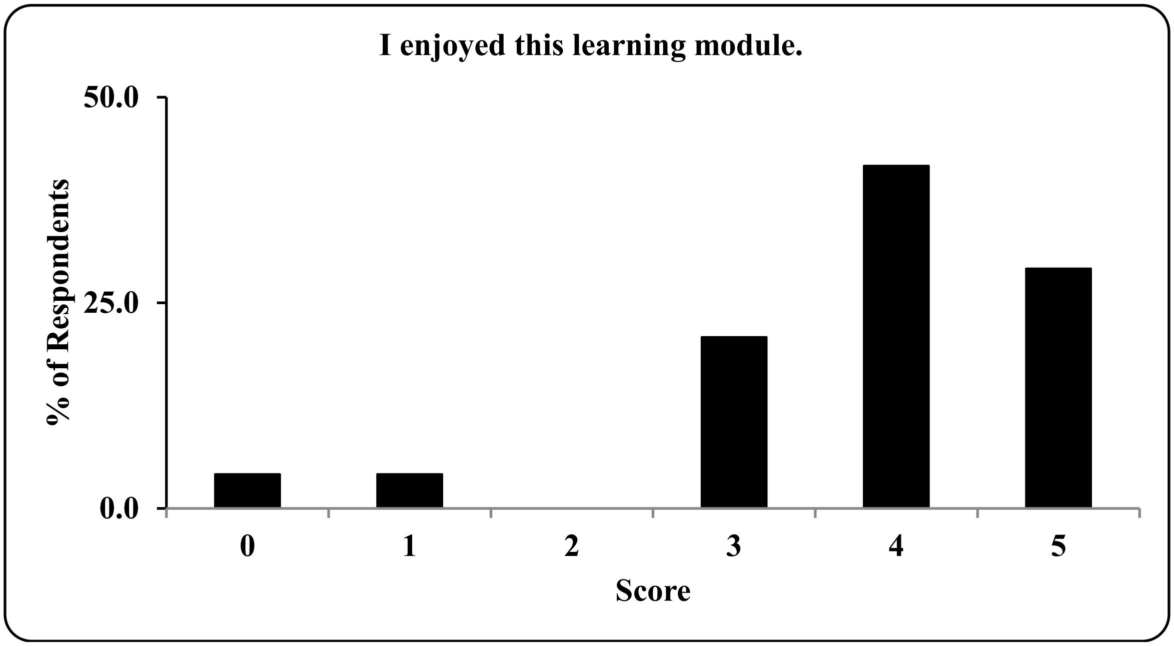


**Figure C. 9** Show the bar plot of % of student responses to the statement: "I enjoyed this learning module," with an average of 3.8 ± 1.2.

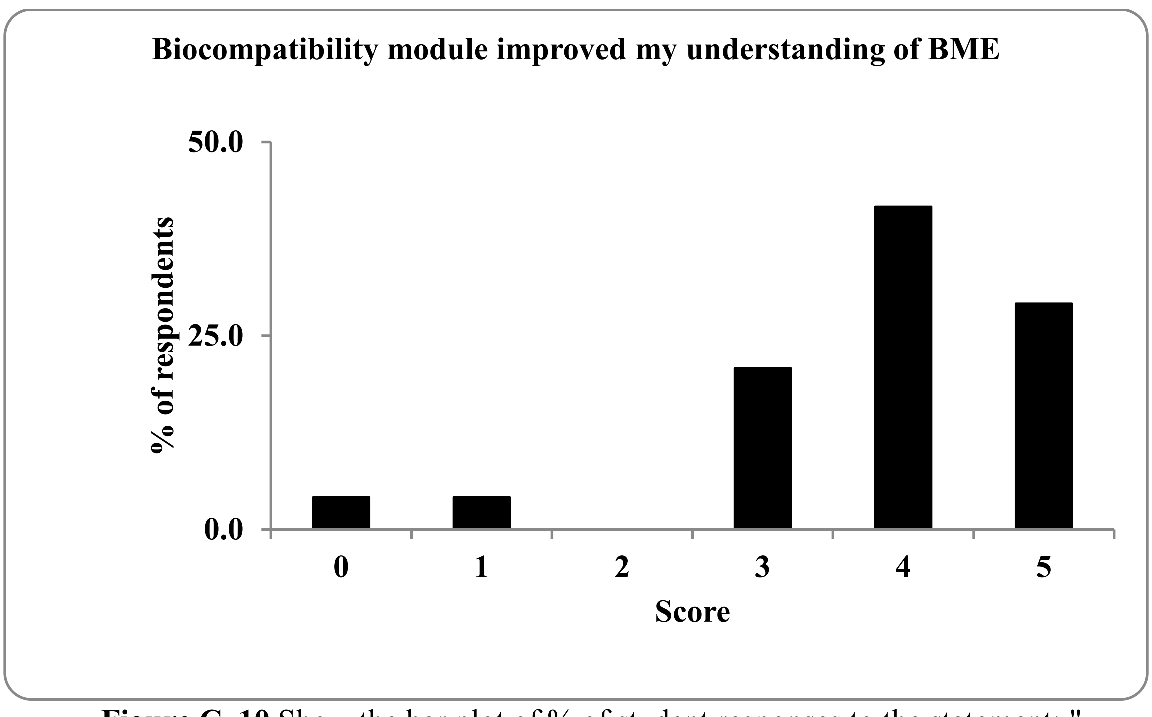


**Figure C. 10** Show the bar plot of % of student responses to the statement: " Biocompatibility module improved my understanding of BME," with an average of 3.8 ± 1.2.

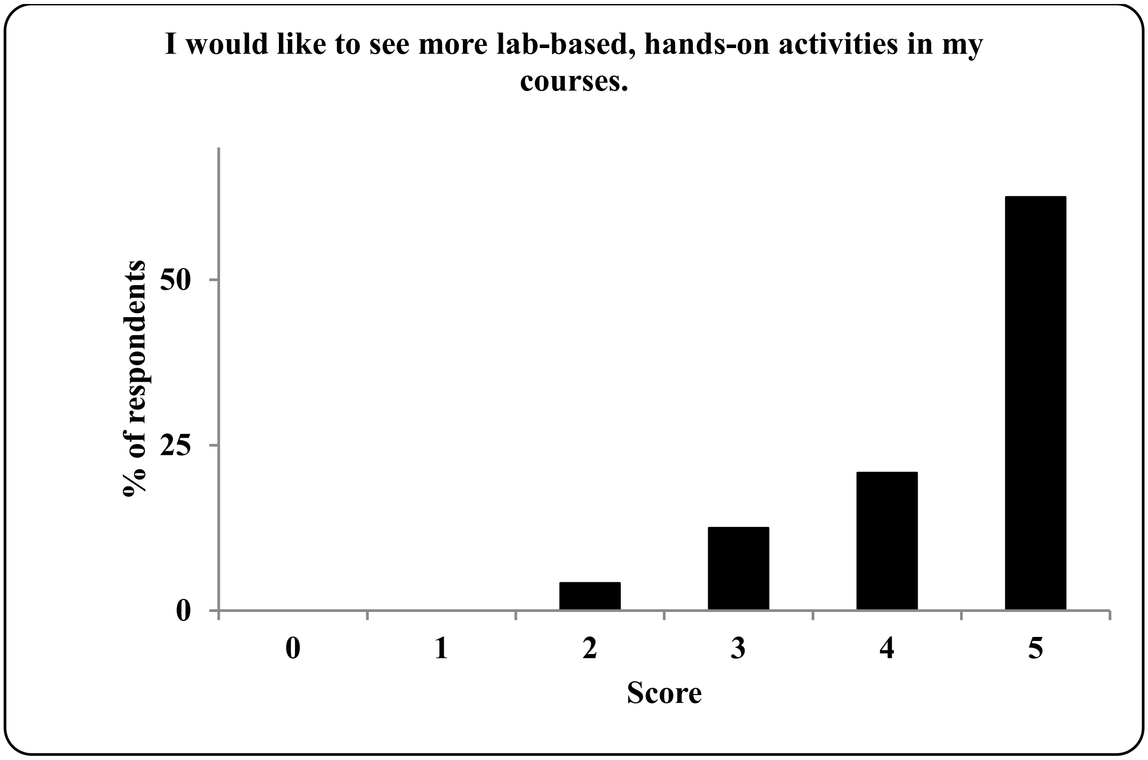


**Figure C. 11** Show the bar plot of % of student responses to the statement: " I would like to see more lab-based, hands-on activities in my courses," with an average of 4.4+/-0.9.

**Appendix D**

Pre-module and post-module Assignment Scoring Rubric used by evaluators for quantitative assessment

| Criterion | 1 - Below Basic | 2 - Basic | 3 - Proficient | 4 - Advanced |
|---|---|---|---|---|
| Data & Entry | Missing device info; fewer than 10 measurements per condition; data not in pairs. | Included required measurements, but the data is unorganized | Correctly recorded all 60 measurements (HR/SpO2) with subject breaks and clear labels. | Data are meticulously organized and include additional notes on testing conditions or device anomalies. |
| Excel Org. (Tasks 1-4) | Failed to aggregate class data or separate into SpO2/HR sheets; missing column labels. | Data is aggregated, but sorting is inconsistent, or columns are difficult to navigate. | All class data was correctly aggregated and sorted into two logical sheets with pairwise columns. | Exceptional spreadsheet "cleanliness"; used advanced formatting or tables for high readability. |
| Plot Quality (Task 5) | Missing plots; axes are swapped; 1:1 correlation line is missing. | Plots present but lack clear titles, color coding, or legible axis labels. | Accurate scatter plots for HR and SpO2; correct axes (Gold-X, Test-Y); includes 1:1 line. | Professional-grade visuals; clear legends; used distinct markers/colors to make trends immediately obvious. |
| Analysis & Recom. (Task 6) | Recommendation is missing or based on personal opinion rather than data. | Recommendation is present but lacks specific references to the plotted trends. | Provides a 2-3 sentence recommendation supported by observable trends in the scatter plots. | Insightful analysis; discusses the "cheap" device's accuracy relative to the 1:1 line across all HR levels. |