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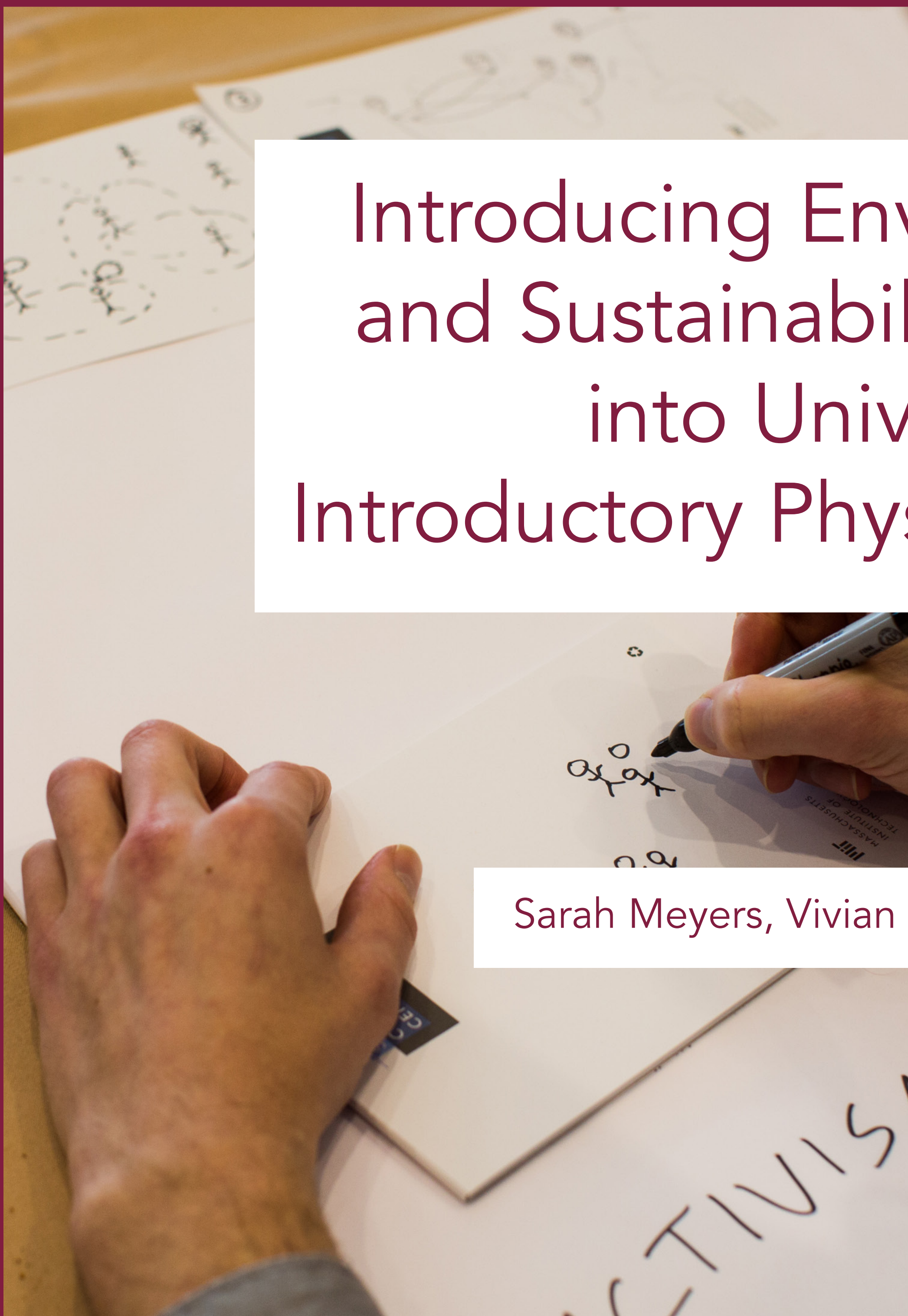

Introducing Environmental and Sustainability Content into University Level Introductory Physics Classes

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Abstract

Although many universities offer climate change, environmental and sustainability-focused courses to students, most students who choose to enroll in these classes may already be passionate about environmental issues. To reach a broader audience, particularly those who are not already sustainability-oriented, the Massachusetts Institute of Technology (MIT) has been infusing sustainability concepts into its General Institute Requirement (GIR) classes, namely those classes that are graduation requirements for all undergraduate students. This paper focuses on an experiment that was conducted within the introductory physics classes at the Massachusetts Institute of Technology. Student environmental actions and attitudes were measured before and after learning different physics concepts through a sustainability lens. Our results showed that after being exposed to sustainability problems and content, students were interested in learning more about topics related to sustainability. However, their environmental actions and attitudes were not significantly impacted.

Keywords: sustainability education, environmental attitudes, environmental actions, STEM, physics

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1 Introduction

As the climate crisis and environmental problems are intensifying, more universities are offering sustainability-focused courses to equip their students with the tools and skills to design and implement solutions. To expose sustainability concepts to a broader cross-section of students, universities can infuse environmental problems into high-enrollment introductory STEM courses. Not only could this infusion strategy change student environmental attitudes and actions, but also applying real world sustainability problems to concepts learned in class can increase the quality of their education. McCright et al. (2013) assert that "STEM education scholars find that learning activities that are hands-on, collaborative, and oriented to real-world problem-solving may be effective in keeping young people in the STEM pipeline" [1]. Indeed, according to Busch (2010), after environmental problems were applied to a physics course in the Georgia College & State University, learning gains increased, 30% more students liked physics, and over 75% of the class thought that real world problems, including the environment, were a definite positive [2].

By infusing real-world environmental issues into required classes for all undergraduates, two mutually reinforcing goals emerge: enhancing environmental learning at MIT and enriching foundational learning. We argue that sustainability infusion into the regular foundational stream of learning links abstract concepts in science, math, and engineering with tangible and immediate environmental problems and provides a powerful mechanism for improving the retention of learning. Additionally, enhanced student appreciation of both sets of content (STEM and sustainability) can motivate students to apply their education to solving global challenges.

However, there is a lack of formal studies on the effect of this sustainability infusion strategy on student environmental actions and attitudes. In this paper, we investigate whether students express interest in learning more about topics related to sustainability after being exposed to sustainability content in their core physics classes, and examine the change in student attitudes and actions towards the environment.

2 Background

2.1 *Sustainability Infusion Project at MIT*

The experiment described in this paper was completed alongside a sustainability infusion project that began in Fall 2019 and has spanned several classes at MIT. Classes were chosen based on the number of enrolled students (approx. 300 - 700) to maximize impact. The classes included in the project were Physics I, Physics II, Calculus, Differential Equations, Introduction to Probability and Statistics, Introduction to Algorithms (computer science), Introductory Biology, Principles of Chemical Science, Introduction to Solid-State Chemistry.

Sustainability infusion consisted of homework and quiz problems that applied the content learned in class to real-world situations. For example, in the chemistry course, students were given goody bags that consisted of take-home experiment materials. One goody bag was centered around reaction rates and the effects of climate change on ocean acidification. In

Probability and Statistics, students were given raw temperature data from the National Oceanic and Atmospheric Administration and asked to accept or reject the hypothesis that Boston has become warmer in the 2000s compared to the 1940s. In Physics II, an hour during class each week is dedicated to group problem solving sessions. One week explored the greenhouse effect through radiative equilibrium and black body radiation.

In this study we describe an experiment we conducted in partnership with Physics I and Physics II. These classes have large numbers of first-year students enrolled, averaging from 550 to 750 students.

2.2 *Defining Sustainability Interest, Environmental Attitudes, and Environmental Actions*

For our purposes, sustainability is defined broadly as including earth science and environmental studies, and a variety of topics including atmospheric sciences, climate change, renewable energy, and biodiversity. Sustainability interest is represented as the level of student curiosity to learn more about sustainability issues. Sustainability interest is separated from environmental attitudes and environmental actions, which serve as metrics for how sustainability-oriented a student is.

Table 1*: Environmental Attitudes and Actions.*

Term	Definition	Reference
environmental attitudes	*A psychological tendency expressed by evaluating the natural environment with some degree of favour or disfavour*	Milfont and Duckitt [12]
environmental actions	*Intentional and conscious civic behaviors that are focused on systemic causes of environmental problems and the promotion of environmental sustainability through collective efforts*	Alisat and Manuel [1]

We define environment attitudes and environmental actions to be consistent with literature as shown in Table 1. Milfont and Duckitt (2009) describe environmental attitudes as "a psychological tendency expressed by evaluating the natural environment with some degree of favour or disfavour" [12]. For example, one dimension of environmental attitudes is “confidence in science and technology, [which is the] belief that human ingenuity, especially science and technology, can and will solve all environmental current problems and avert or repair future damage or harm to the environment, versus [the belief] that human ingenuity, especially science and technology cannot solve all environmental problems.”

Likewise, we define environmental actions to be consistent with literature. Alisat and Riemer (2015) define environmental actions as "intentional and conscious civic behaviors that are focused on systemic causes of environmental problems and the promotion of environmental sustainability through collective efforts". Examples of environmental actions include “educated myself about environmental issues,” “participated in an educational event,” “organized an educational event,” and “used traditional methods (e.g. letters to the editor, articles).” Alisat and Riemer categorize environmental actions as either participatory actions or leadership actions. Changing personal habits (e.g., switching to public transportation, or recycling) is not included in their scale of environmental actions, and therefore is not within the definition of environmental actions as used in this paper. Behaviors are described by direct actions, in contrast to environmental values, identity, or intentions [1].

Within the scope of these definitions, the goal of this study was to measure student interest in sustainability topics and how environmental attitudes and actions might be affected after students were exposed to sustainability concepts in their core classes.

2.3 How Education May Affect Environmental Attitudes and Actions

Interest in environmental topics is separated from environmental attitudes and environmental actions because their relationship is complex. Some researchers believe that worldviews and political orientation are more closely correlated with belief in climate change than education and subjective knowledge [16] [6]. Likewise, Kahan et al. and McKenzie-Moore assert that education does not increase environmentally friendly behavior [11] [7]. In contrast, Shi et al. found that more knowledge about the causes of climate change correlated with more concern [15]. Furthermore, Clayton et al. claim that "public attitudes about climate change can be successfully 'inoculated' against misinformation by exposing people to a dose of refuted arguments before they hear them" [3]. Indeed, according to a survey conducted by Hess and Maki for US college students, almost one-third of students with a conservative political orientation, which is correlated with lower levels of belief in human-caused climate change, increased their beliefs in human-caused climate change after taking climate-related courses [5]. We recognize that environment topics and climate change are related but not necessarily overlapping issues, and that climate change is considerably more polarizing than a range of environmental issues. Even so, research shows that this question about the relation between one's attitudes and one's behavior is consistently complex for both topics. Different researchers disagree about the impact that knowledge can have on an individual's attitudes and behavior.

The studies about how environmental factors are affected by education are equally inconsistent. Levine and Strube found that knowledge independently predicted behavior, but knowledge didn't predict attitudes [8]. In contrast, Paço and Lavrado state that there is no correlation between knowledge and attitude, or knowledge and behavior [13]. Yet, according to Haider et al., an increase in knowledge helped to change environmental attitudes in office employees [4]. Within a school context, a study by Marzetta indicated that based on quantitative results from the Climate Change Beliefs and Behavior Survey, students did not improve after taking an environmental course. However, qualitative results (open-ended comments) suggested that students became more aware of environmental issues [9]. Continuing with these conflicting results, Rosentrater and Burke found that students wanted to reduce their carbon footprint and help the environment, but they were unwilling to pay money or commit to changing their habits, which suggests a discrepancy between environmental intentions and environmental behavior [14]. Thus, there is no consensus on the effect of knowledge on environmental behavior and attitudes, perhaps because comparison across studies is nearly impossible since external variables are uncontrolled for.

Because there is disagreement among the scientific community as to whether education can alter environmental attitudes and actions, we separated interest in sustainability-related topics from environmental attitudes and actions. In this experiment, we aimed to show instructors which topics students were interested in learning more about to enhance their education while measuring whether the infusion of these topics affected student environmental attitudes or actions. Additionally, this study further explored the relationship between knowledge and environmental attitudes and actions through the context of sustainability infusion into core curricula, rather than sustainability-focused classes as in the literature.

On top of concerns related to how education may affect environmental attitudes and actions, content that is not well-aligned with a course curriculum can impact student attitudes negatively. For example, adding labs that are too scripted for students can lead to negative attitudes about science and the scientific method generally. Thus, in measuring environmental attitudes and actions, we must test the hypothesis that they may be negatively affected by infusing sustainability-related content.

3 Methodology

3.1 Surveying Environmental Attitudes and Actions

There were two null hypotheses for this study. First, students would take no interest in topics relating to sustainability. Second, after being exposed to sustainability material in their classes, students would not show increased environmental actions or attitudes.

At the beginning of the term, students were sent an online survey to gather an initial baseline of their environmental actions and attitudes. Responses were voluntary, and students were incentivized to complete the survey with an entry for a $100 gift card raffle. The survey (Appendix A, B) consisted of relevant questions from the Environmental Action Scale (EAS) [1] and Environmental Attitudes Inventory (EAI) [12]. At the end of the course, students took the same survey again to re-evaluate their environmental actions and attitudes, with the same incentive in place. Additionally, students were asked about their interest in different topics proposed by the physics instructors.

3.2 Student Population

The study population was the undergraduate students enrolled in 8.01 Physics I, 8.01L Physics I, and 8.02 Physics II during Fall 2020 at MIT. 8.01 Physics I introduces classical mechanics, and 8.02 Physics II is introduction to electricity and magnetism; the difference between 8.01 and 8.01L is that 8.01L is taught for an extra month. 8.01 had 531 students, 8.02 had 218 students, and 8.01L had 79 students.

In this experiment, 8.01L was used as the control group. In the first survey delivered at the beginning of the course, the response rate was 31.6% for 8.01L, 24.1% for 8.01, and 14.7% for 8.02. In the second survey delivered at the end of the course, the response rate was 36.7% for 8.01L, 33.7% for 8.01, and 19.3% for 8.02. Age, income level, and gender identity were not asked, as Hornsey et al. found that these variables had relatively small effects on belief in climate change [6].

The majority of undergraduates enrolled in 8.01, 8.01L and 8.02 during the Fall 2020 at MIT were first-year students in the Class of 2024. The Class of 2024 consists of 1,071 undergraduates in total, where 49% identify as female, 51% identify as male, and less than 1% identify as another gender identity. Also, students self-identify as: American Indian/Alaskan Native 2%, Asian American 42%, Black/African American 11%, Hispanic/Latinx 14%, Native Hawaiian/Pacific Islander 1%, and White/Caucasian 39% (total exceeds 100% of class because students may indicate more than one race/ethnicity).

3.3 Physics I and II Course Organization

The courses were taught online, as the majority of students were restricted from in-person classes due to the pandemic caused by SARS-CoV-2. For 8.01 and 8.02, the online class structure consisted of four prerecorded, asynchronous learning sequences and one synchronous online section with faculty each week. On Fridays, an hour was dedicated to online problem-solving, in which students worked in groups of three and practiced the concepts they had learned with the help of undergraduate teaching assistants. A homework problem set was assigned and due each week. For 8.01L, the class structure was traditional lecture style. We recognize that an uncontrolled variable is the class structure between the experimental groups (8.01 and 8.02) compared to the control group (8.01L), but this was unavoidable. The curriculum across all sections for the same class must be the same. It would be unreasonable to give students taking the same class in different sections different learning experiences, and changing the class structure would overwhelm the instructors.

In 8.01, sustainability infusion consisted of one homework problem about the absorption of carbon dioxide by the Amazon rainforest, one homework problem about automobile energy efficiency, one homework problem on windmill efficiency, and one full week of class pre-lecture assignments and in-class activities on rotating reference frames and their effect on weather. In 8.02, a problem set consisting of three problems covered the greenhouse effect, and a lab experiment was conducted on electrical power generation.

3.4 Statistical Analysis

From the overall survey participants, two separate populations were identified. The first ($n = 90$) consists of students who took both the first and second survey. The second consists of students who only either took the first survey at the beginning of the semester ($n = 163$) or the second survey at the end of the semester ($n = 95$).

The null hypothesis was that the experimental group would not see significantly more or less change in their EAI and EAS means across the semester than the control group. The alternative hypothesis was that the EAS and EAI mean differences would be greater for the control group than the experimental group. As seen in the evaluation of EAS and EAI instruments, a significant difference in scores is defined by an absolute difference of at least 0.5 out of a 7-point scale.

For the EAI questions, questions and their reversals were selected from four different scales (see Appendix A). The reversals were included in the survey to increase reliability of students' self-reporting. For each pair, the scores for the reverse questions were reversed and averaged with their counterparts.

4 Results and Analysis

4.1 Free-Response and Class Questions

In the second survey, in addition to the questions asked in the first survey to measure student environmental attitudes and actions, students were asked about what topics they were interested in learning more about.

Q17 ("I was inspired to learn more about a topic covered in at least one of the homework problems") was free-response. Out of the 37 responses the question received, 43% of students replied with topics that related to environmental problems. The answers ranged from biodiversity and atmospheric physics to alternative energy sources and the food industry's effect on the environment. Thus, because 16 out of the 185 students who participated in the second survey answered they were inspired to learn more about environmental topics from the homework, almost a tenth of the sample population noticed the sustainability infusion and were motivated to educate themselves about these topics.

For Q18 ("I would have liked to learn more about..."), students could select multiple answers. The choices are listed on the x-axis of the graph in Fig 1. The most popular topic was the physics of energy, representing approximately half of the students who responded to this question. The physics of energy was introduced in Physics I via the Betz Limit and the concept of utilizing wind as a renewable energy source. The second most popular topic, selected by slightly less than half the students, was the effects of climate change, which manifested itself through problems related to hurricane velocity and sea level rise. Therefore, Q18 shows that students are indeed interested in learning more about the environment through a physics context.

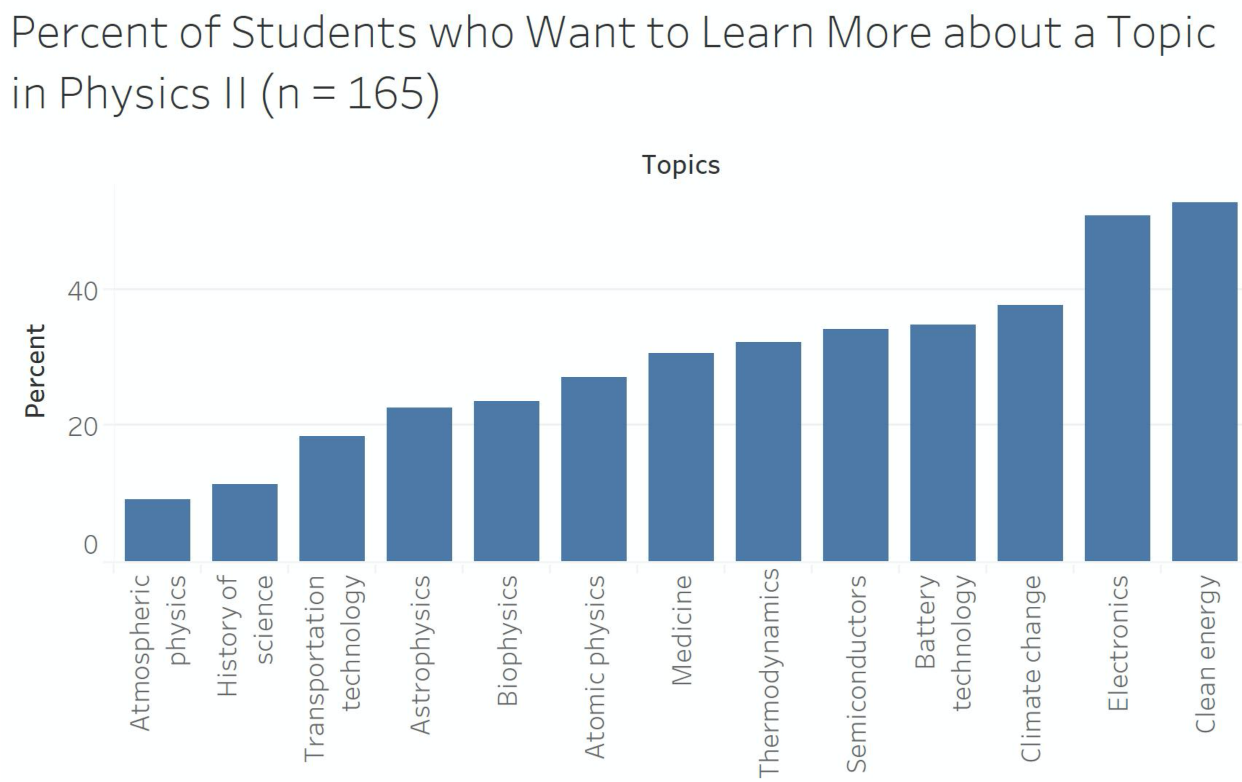


***FIG 1:** Students were free to select among a list of topics shown on the x-axis what they wished they had learned more about after completing Physics I. Students could select as many topics as they desired.*

This interest in sustainability is further reinforced in Q19 ("Next semester in 8.02, I am looking forward to learning more about"). As seen in Fig 2, more than half the students were interested in learning more about clean energy, which is consistent with how students wanted to learn more about the physics of energy given their exposure to renewable wind energy. Electronics was the second most popular topic. The third and fourth most popular topics were climate change and battery technology, both of which are related to current sustainability concerns and solutions.

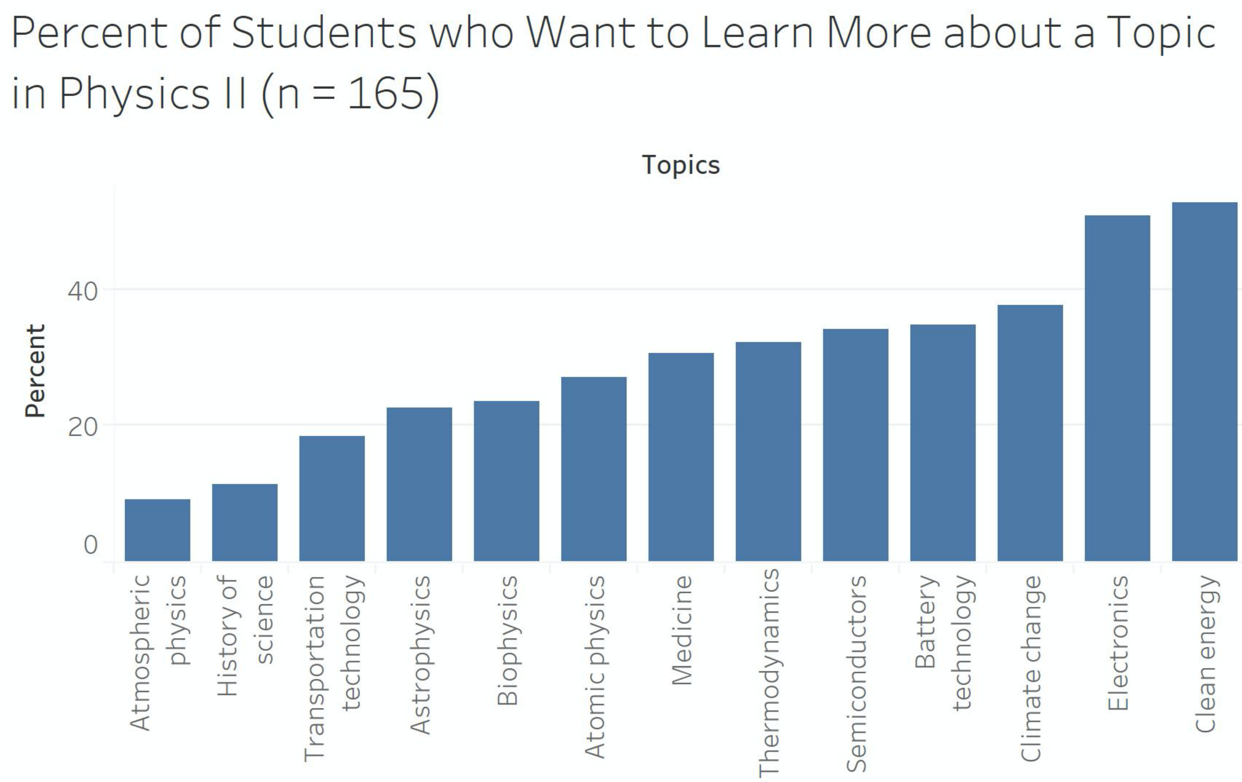


FIG 2: *Students were free to select among a list of topics shown on the x-axis what they would be interested in learning more about in the next physics class (Physics II: Electricity and Magnetism) after completing Physics I. Students could select as many topics as they desired.*

4.2 Environmental Attitudes

There was not a significant difference between the average change in EAI scores for the control compared to the experimental. This may be partly due to the small size of the control. Only 14 students filled out both Survey 1 and Survey 2. In the non-repeating population of the control, another 15 students filled out Survey 1 and 11 students filled out Survey 2. Thus, because the control sample size was small, the standard error was often larger than the difference between the average change in EAI scores for the control and the experimental group, making it difficult to draw conclusions from the results. Nonetheless, while conclusions from these very small sample sizes cannot be drawn, this white paper is intended to record the experiment as it was conducted and suggest next steps for understanding the relationship between learning, attitudes and actions.

4.2.1 Overlapping Study Results

As seen below (Fig 3), for all questions except for 6_1 and 6_12 (questions can be found in Appendix A), the control group saw a greater increase or a smaller decrease in the average EAI scores from the first survey to the second compared to the experimental group.

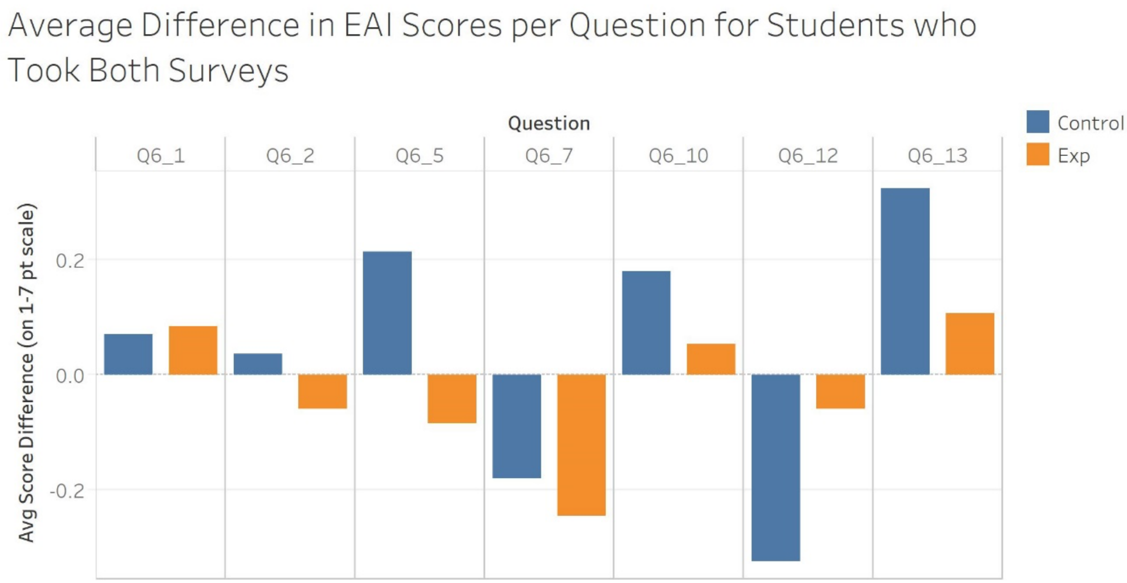


FIG 3: *The questions on the x-axis represent different questions from the original EAI survey student were asked. On the y-axis is the average difference in scores from Survey 1 to Survey 2. The blue bars denote the control group, while the orange bars denote the experimental group. The sample size of the control was 14 students, while the experimental group was 76 students.*

In Question 6_12 ("Humans are severely abusing the environment"), although the average EAI score decreased for both the control and experimental group, the average difference for the experimental group was -0.06, compared to -0.32 for the control (Table 1). Therefore, on average, students in the experimental group believed in this statement less than students in the control group. However, the absolute difference between the control and experimental differences is only 0.26, which is approximately a 4% difference on the 1-7 point scale. Therefore, the change is not significant, as it is below 0.5 as defined in our hypothesis, and the null hypothesis is accepted.

This difference is even less significant in Q6_1 ("Controls should be placed on industry to protect the environment from pollution, even if it means things will cost more"). Because a difference of 0.01 is less than a 1% difference on the 1-7 point scale, the null hypothesis is accepted.

As seen in Table 2, due to the smaller size of the control group, the standard error is about 1.4 to 2.6 times the standard error of the experimental group. Additionally, the control's standard error is greater than the average difference in EAI scores per question between the control and experimental groups. Thus, because of the small size of the control group, it is not possible to draw conclusions from the data.

Table 2: *EAI descriptive statistics and calculations for the overlapping population of students.*

Question	Q6_1	Q6_2	Q6_5	Q6_7	Q6_10	Q6_12	Q6_13
Exp S1 Avg	5.70	5.97	5.11	3.95	3.55	6.25	4.93
Exp S2 Avg	5.78	5.91	5.02	3.70	3.60	6.19	5.03

Exp Avg EAI Diff	0.09	-0.06	-0.09	-0.24	0.05	-0.06	0.11
Control S1 Avg	6.11	6.07	5.07	3.82	3.57	6.71	4.54
Control S2 Avg	6.18	6.11	5.29	3.64	3.75	6.39	4.86
Control Avg EAI Diff	0.07	0.04	0.21	-0.18	0.18	-0.32	0.32
Exp Avg Diff - Control Avg Diff	0.01	-0.09	-0.30	-0.06	-0.13	0.26	-0.22
Exp Diff SE	0.11	0.13	0.10	0.14	0.13	0.11	0.12
Control Diff SE	0.16	0.27	0.22	0.28	0.33	0.17	0.29
Control Diff SE / Exp Diff SE	1.43	2.09	2.19	2.02	2.60	1.57	2.44

4.2.2 Non-Overlapping Study Results

In the non-overlapping study, although both the experimental and control groups saw decreases in their average EAI scores, for questions 6_1, 6_2, 6_5, 6_12, and 6_13, the experimental average EAI did not decrease as much as that of the control (Fig 4). The results are presented in Table 3. Because the control sample size of the population was small, normality was not assumed, and the standard error was not calculated for the combination of the first and second survey populations. Instead, the results were compared with the results of the repeating survey to derive context if the average differences between the control and experimental average EAI scores per question was significant or not.

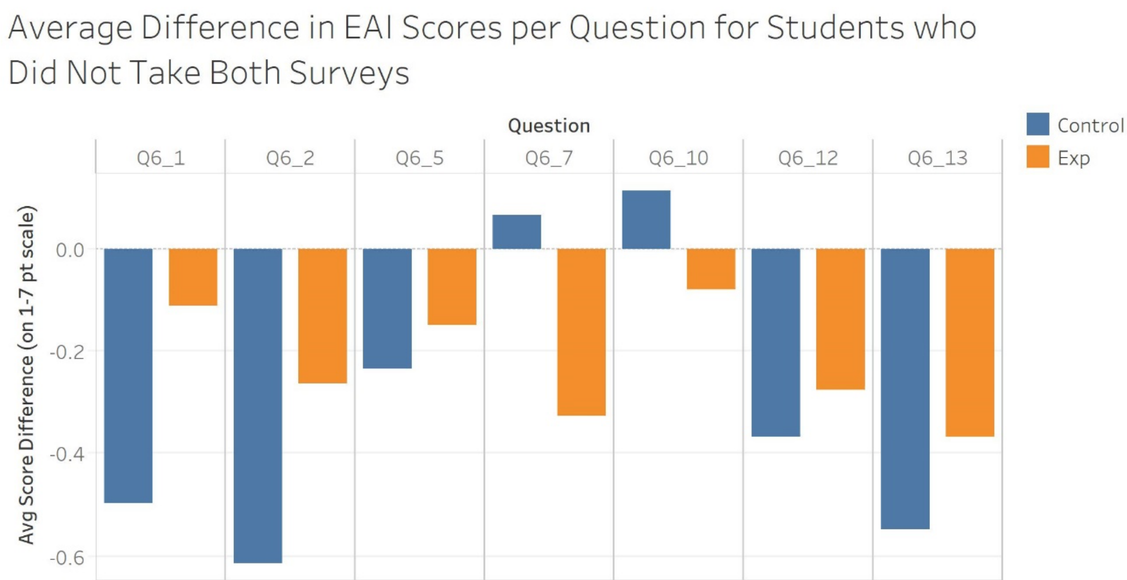


FIG 4: *The questions on the x-axis represent different questions from the original EAI survey student were asked. On the y-axis is the average difference in scores from Survey 1 to Survey 2. The blue bars denote the control group, while the orange bars the experimental group. The sample size of the control was 14 students, while the experimental group was 76 students. For the first survey, the sample population for the control was 15 students, and the experimental group was 145 students. For the second survey, the sample population for the control was 11 students, and the experimental group was 84 students.*

Table 3: *EAI descriptive statistics and calculations for the non-overlapping population of students.*

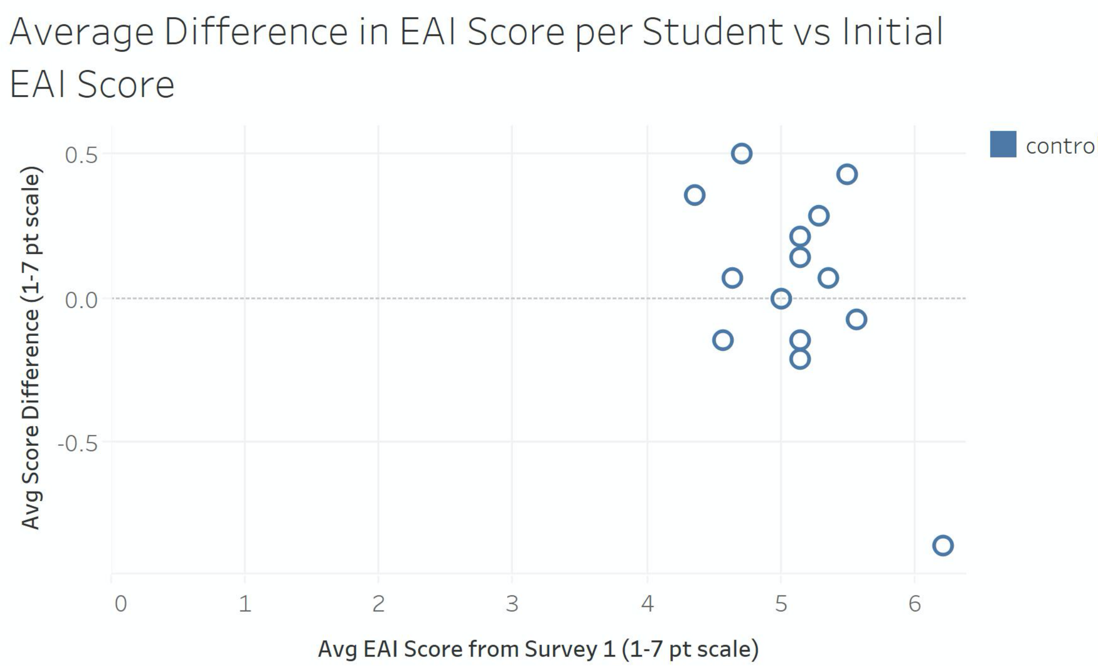
Question	Q6_1	Q6_2	Q6_5	Q6_7	Q6_10	Q6_12	Q6_13
Exp S1 Avg	5.76	6.06	5.05	4.22	3.74	6.28	5.18
Exp S2 Avg	5.64	5.79	4.90	3.89	3.67	6.01	4.81
Exp Diff Avg	-0.11	-0.26	-0.15	-0.32	-0.08	-0.28	-0.37
Control S1 Avg	5.63	6.07	4.73	4.43	3.93	6.37	5.37
Control S2 Avg	5.14	5.45	4.50	4.50	4.05	6.00	4.82
Control Diff Avg	-0.50	-0.61	-0.23	0.07	0.11	-0.37	-0.55
Exp Avg Diff - Control Avg Diff	0.38	0.35	0.08	-0.39	-0.19	0.09	0.18

4.2.3 Comparison of Overlapping and Non-Overlapping Studies

The only result that was consistent between the overlapping and non-overlapping studies was for Q6_12, in which the experimental group saw a more positive increase in scores compared to the control group. This repeated result indicates that perhaps students in the experimental group were exposed to problems of alternative energy resources, such as wind power, which offered more optimism and a greater sense of self-efficacy, and thus they believed in this statement less than the students in the control group.

However, the results are less consistent between the two studies for the rest of the questions. For example, as seen in Fig 3 and 4, although the average EAI scores for both the experimental and control groups increased for questions 6_1 and 6_2 in the overlapping study, the scores for the same question decreased for the non-overlapping study. The greatest difference between the control and experimental group differences in average EAI scores was 0.39, which is less than 0.5 cutoff set by the hypothesis.

Additionally, as seen in Fig 5, there does not seem to be a correlation between the initial EAI score and the difference in EAI scores for each student. Therefore, students with higher or lower EAI scores at the beginning of the semester were approximately equally likely to increase or decrease their scores.



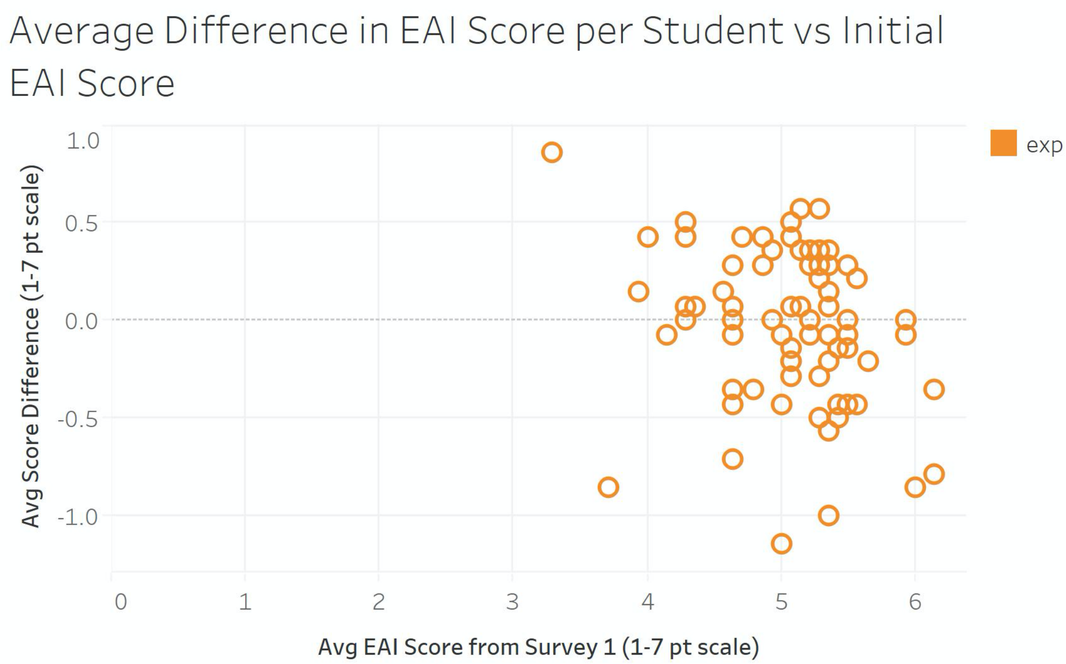


***FIG 5:** This figure shows the average EAI score per question for the 90 students who took both surveys. The top graph shows the results of the 14 students in the control, and the bottom graph shows the results of the 76 students in the experimental group.*

Therefore, the second null hypothesis, that there is no significant difference between the mean environmental attitudes difference for the control and experimental groups, is accepted.

4.3 Environmental Actions

As with the EAI results, the EAS results did not show any major differences in the average difference of scores between the control and experimental group (Table 3). While there is an observable difference, nothing can be inferred given the smaller sample size and confounding variables.

4.3.1 Results for Overlapping Study

As seen in Fig 6, the control group sees a greater increase in the average EAS score in the second survey compared to the first survey than the experimental group in all the questions except Q5_6 ("Became involved with an environmental group or political party"). (In Q5_1 ("Educated myself about environmental issues"), the difference between the first and second sores was only 0.006, essentially the same between the control and experimental groups). However, as seen in Table 3, the standard error of the control is usually greater than the difference between the experimental and control values, save for questions Q5_5 ("Used online tools (e.g., YouTube, Facebook, Wikipedia) to raise awareness about environmental issues.") and Q5_7 ("Participated in an in-person or online community event which focused on environmental awareness.").

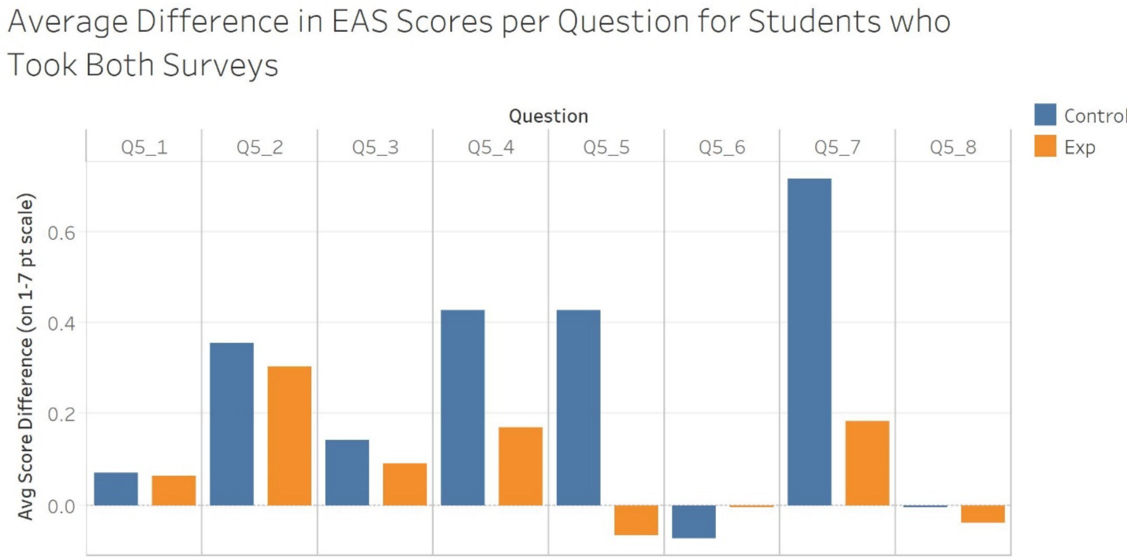


FIG 6: *The questions on the x-axis represent different questions from the original EAS survey student were asked. On the y-axis is the average difference in scores from Survey 1 to Survey 2. The blue bars denote the control group, while the orange bars the experimental group. The sample size of the control was 14 students, while the experimental group was 76 students.*

For Q5_5, the control difference was more positive than the experimental difference by 0.49, while the control group's standard error is 0.39. For Q5_7, the control difference is more positive than the experimental difference by 0.53, while the control group's standard error is 0.35 (Table 4). This suggests that the control group participated in more environmental actions at the end of the semester compared to the beginning of the semester than the experimental group. However, although the second null hypothesis appears to be accepted overall, the non-overlapping study presents drastically different results.

Table 4: *EAS descriptive statistics and calculations for the overlapping population of students.*

Question	Q5_1	Q5_2	Q5_3	Q5_4	Q5_5	Q5_6	Q5_7	Q5_8
Exp S1 Avg	4.16	1.89	1.32	4.19	2.09	1.78	1.67	1.67
Exp S2 Avg	4.22	2.18	1.41	4.32	2.03	1.78	1.86	1.63
Exp Avg EAS Diff	0.07	0.29	0.09	0.13	-0.07	0.00	0.18	-0.04
Control S1 Avg	3.93	1.64	1.21	4.00	2.00	2.29	1.64	1.79
Control S2 Avg	4.00	2.00	1.36	4.43	2.43	2.21	2.36	1.79
Control Avg EAS Diff	0.07	0.36	0.14	0.43	0.43	-0.07	0.71	0.00
Exp Avg Diff - Control Avg Diff	-0.01	-0.07	-0.05	-0.30	-0.49	0.07	-0.53	-0.04
Exp Diff SE	0.15	0.22	0.15	0.17	0.20	0.20	0.24	0.19
Control Diff SE	0.40	0.20	0.21	0.44	0.39	0.35	0.35	0.48

Control Diff SE / Exp Diff SE	2.59	0.92	1.41	2.53	1.98	1.78	1.48	2.57

4.3.2 *Results for Non-Overlapping Study*

In contrast to the EAS results presented in the overlapping study, in the non-overlapping study, the experimental group scores on average increased for each question, while the control group average scores decreased, except for Q5_1, in which the control group average stayed about the same, as seen in Fig 7.

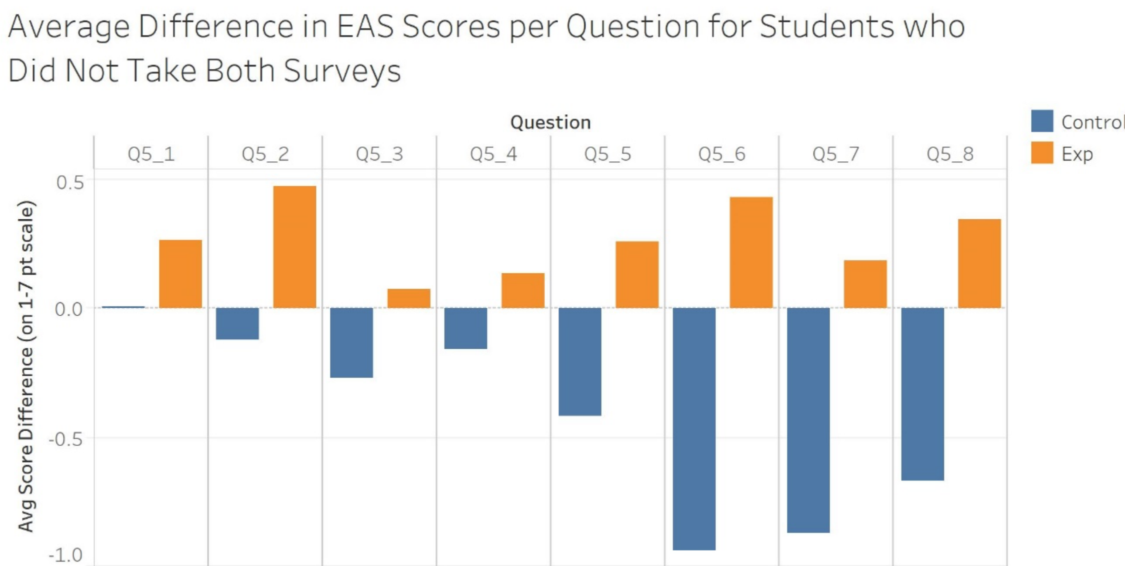


FIG 7: *The questions on the x-axis represent different questions from the original EAS survey student were asked. On the y-axis is the average difference in scores from Survey 1 to Survey 2. The blue bars denote the control group, while the orange bars denote the experimental group. The sample size of the control was 14 students, while the experimental group was 76 students. For the first survey, the sample population for the control was 15 students, and the experimental group was 145 students. For the second survey, the sample population for the control was 11 students, and the experimental group was 84 students.*

As seen in Table 5, the differences between the change in the experimental group's average scores and the control group' average scores range from 0.26 to 1.37. For questions 5_6, 5_7, and 5_8 ("Spent time working with a group/organization that deals with the connection of the environment to other societal issues such as justice or poverty."), this difference between the control group and experimental group is greater than 1 on a scale of 1-7. This would suggest that the experimental group saw a significant increase in these three actions on average, although the results are puzzling when coupled with those of the overlapping study.

Table 5: *EAS descriptive statistics and calculations for the non-overlapping population of students.*

Question	Q5_1	Q5_2	Q5_3	Q5_4	Q5_5	Q5_6	Q5_7	Q5_8
Exp S1 Avg	4.26	2.16	1.43	4.48	2.29	1.88	1.88	1.72
Exp S2 Avg	4.52	2.63	1.51	4.62	2.55	2.31	2.07	2.07
Exp Diff Avg	0.27	0.47	0.08	0.14	0.26	0.43	0.19	0.35
Control S1 Avg	4.27	1.67	1.27	4.07	1.87	1.93	1.87	1.67
Control S2 Avg	4.27	1.55	1.00	3.91	1.45	1.00	1.00	1.00
Control Diff Avg	0.01	-0.12	-0.27	-0.16	-0.41	-0.93	-0.87	-0.67
Exp Avg Diff - Control Avg Diff	0.26	0.59	0.34	0.29	0.67	1.37	1.06	1.01

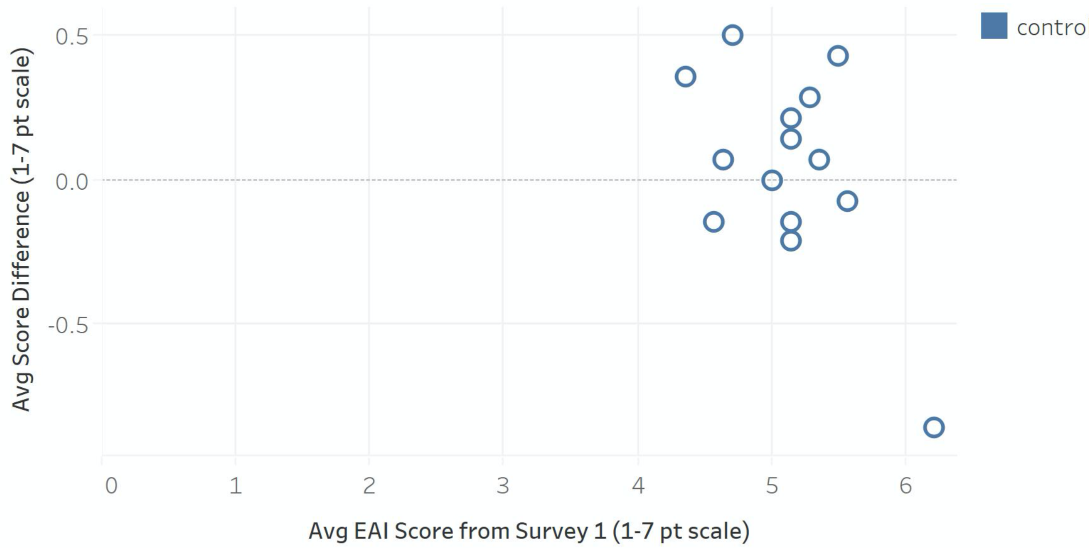
4.3.3 Comparison of Overlapping and Non-Overlapping Studies

Strangely, the results of the overlapping and non-overlapping studies contradict each other. In the overlapping study, the null hypothesis that the experimental group would not see a greater increase in their EAS scores compared to the control group is accepted. However, for the non-overlapping study, the null hypothesis is rejected. One possible reason for this discrepancy is the random samples happened to be very different, which is made more possible by the small size of the control.

However, unlike with the EAI scores, there appears to be a slight negative correlation between the initial EAS score and the difference in scores after the second survey in the experimental group, as seen in Fig 8. This slightly negative correlation is expected as a regression towards the mean: students with higher scores at the start of the semester are more likely to decrease in EAS scores because it takes more effort to maintain their high scores, while students with lower scores at the start of the semester are more likely to increase in EAS scores because it takes less effort to increase their scores.

Twenty out of the ninety students, almost a quarter of the sample population, had a significant increase (>= 0.5) in their EAS scores. Although the environment was not controlled, it is impossible to isolate this increase in EAS scores to solely the infusion of sustainability education into the physics curriculum. In future work, it would be interesting to repeat this study to get a larger sample size and to include interviews with students to ask directly to what degree they believe their gained knowledge in sustainability through infusion of their core curricula classes contributed to their change in behavior related to the environment.

Average Difference in EAI Score per Student vs Initial EAI Score



Average Difference in EAS Score per Student vs Initial EAS Score

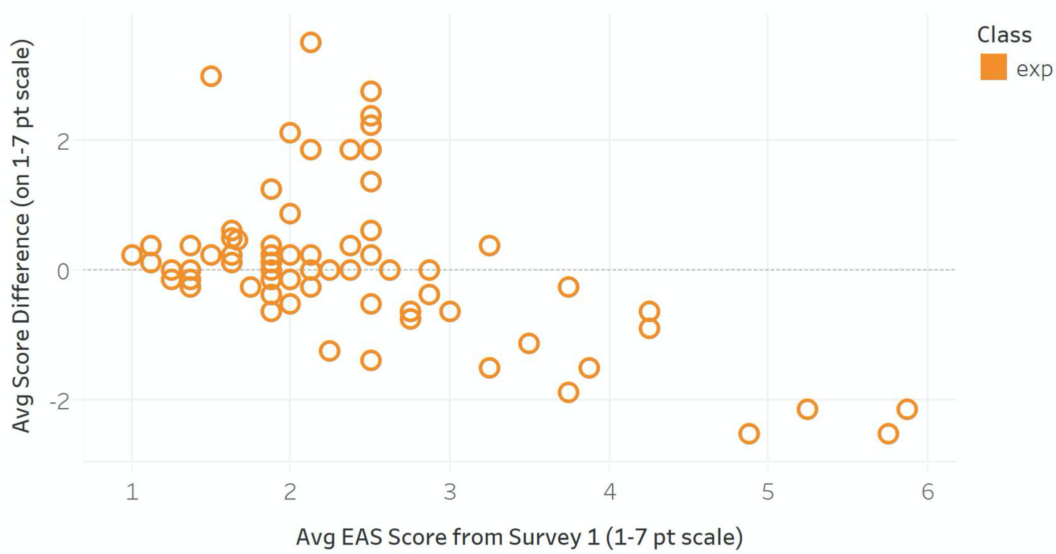


FIG 8: *This figure shows the average EAS score per question for the 90 students who took both surveys. Each dot on this graph represents a student's initial EAS average score on the x-axis and their change in EAS score from the end of the semester compared to the beginning of the semester on the y-axis. The top graph shows the results of the 14 students in the control, and the bottom graph shows the results of the 76 students in the experimental group.*

5 Conclusion

In summary, the study revealed some early evidence that a general interest to learn more about sustainability increased after MIT students enrolled in an introductory physics class were exposed to topics in sustainability through homework problems and group problems. However, no evidence was found to indicate any change in environmental attitudes or actions on average. Infusing sustainability into application problems in mainstream classes is likely an important strategy to use given the body of research that shows that increased environmental education leads to action. However, this study cannot substantiate that claim within the constraint of this study. Future work should be expanded to enable more rigorous research to derive more robust results.

The authors wish to acknowledge the significant limitations of this study. The small sample sizes, especially for those students enrolled in 8.01L, compromised the ability to reach meaningful conclusions across the control and experimental groups. Also, the limited time frame for the study severely constrained the bounds for allowing meaningful changes in student attitudes and actions to be exhibited and recorded. As a result, this study cannot be used to arrive at conclusions about the efficacy of introducing sustainability and environmental topics into STEM classes broadly.

Future work is needed to produce robust conclusions useful to advance effective pedagogy. Larger sample sizes, much greater response rates and standardized measures of the effects of sustainability learning are necessary to establish unbiased and actionable conclusions free from confounding variables.

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7 Conflict of Interest Disclosures

None reported.

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8 Appendix: Survey Questions

A Environmental Attitudes Survey Questions Used

The below represents a subset from the Environmental Attitudes Survey developed by Milfont and Duckitt [12]. To limit the amount of time necessary to complete the survey and increase participation rates, the following subset was chosen determined to be most relevant to university students.

*R = reverse of the above

Scale 2 - Support for interventionist conservation policies
- ***Q6_1:*** Controls should be placed on industry to protect the environment from pollution, even if it means things will cost more.
- ***Q6_4:*** Industries should be able to use raw materials rather than recycled ones if this leads to lower prices and costs, even if it means the raw materials. (R)
- ***Q6_2:*** The government should give generous financial support to research related to the development of alternative energy sources, such as solar energy.
- ***Q6_3:*** It is wrong for governments to try and compel business and industry to put conservation before producing goods in the most efficient and cost effect. (R)

Scale 3 - Environmental movement activism
- ***Q6_5:*** I would like to join and actively participate in an environmentalist group.
- ***Q6_6:*** I would NOT get involved in an environmentalist organization. (R)

Scale 5 - Confidence in science and technology
- ***Q6_7:*** Science and technology will eventually solve our problems with pollution, overpopulation, and diminishing resources.
- ***Q6_9:*** We cannot keep counting on science and technology to solve our environmental problems. (R)
- ***Q6_8:*** Science and technology do as much environmental harm as good.
- ***Q6_10:*** Humans will eventually learn enough about how nature works to be able to control it. (R)

Scale 6 - Environmental threat
- ***Q6_13:*** When humans interfere with nature, it often produces disastrous consequences.
- ***Q6_14:*** The idea that the balance of nature is terribly delicate and easily upset is much too pessimistic. (R)
- ***Q6_12:*** Humans are severely abusing the environment.
- ***Q6_11:*** I do not believe that the environment has been severely abused by humans. (R)

B Environmental Action Scale Questions Used

The below represents a subset from the Environmental Action Scale developed by Alisat and Riemer [1]. To limit the amount of time necessary to complete the survey and increase participation rates, the following subset was chosen determined to be most relevant to university students. Additionally, some questions were not used from the original scale because of the limitations on certain actions during the Covid-19 pandemic.

- *Q5_1:* Educated myself about environmental issues (e.g., through media, television, internet, blogs, etc.).
- *Q5_2:* Participated in an educational event (e.g., workshop) related to the environment.
- *Q5_3:* Organized an educational event (e.g., workshop) related to environmental issues.
- *Q5_4:* Talked with others about environmental issues (e.g., spouse, partner, parent(s), children, or friends).
- *Q5_5:* Used online tools (e.g., YouTube, Facebook, Wikipedia) to raise awareness about environmental issues.
- *Q5_6:* Became involved with an environmental group or political party (e.g., volunteer, summer job, etc.).
- *Q5_7:* Participated in an in-person or online community event which focused on environmental awareness.
- *Q5_8:* Spent time working with a group/organization that deals with the connection of the environment to other societal issues such as justice or poverty.