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Longitudinal Study of the Impacts of a Climate Change Curriculum on Undergraduate Student Learning: Initial Results

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Abstract: The present study assesses the efficacy of a semester-long undergraduate sustainability curriculum designed from a systems approach. The three-course curriculum, which incorporated environmental science and ethics courses along with an integrative course using a community-based learning pedagogy, was intended to provide students with experience using knowledge and skills from distinct disciplines in a holistic way in order to address the complex problems of the human acceptance of and response to anthropogenic climate change. In the fall of 2013, 23 of the 24 sophomore general education students enrolled in the three courses were surveyed at the beginning and end of the semester; 17 of those same students completed the survey again in the spring of 2016, their senior year. Results, which focus on the 17 students who continued to participate through their senior year, were analyzed with quantitative and qualitative methodologies. The pre/post data from the surveys demonstrated significant improvement in climate literacy, certainty, concern and urgency over the course of the semester; the senior data indicated that those improvements were largely retained. The study also suggests that the nine-credit curriculum improved transferable skills such as interdisciplinary thinking, self-confidence and public speaking. A qualitative analysis of three student cases, informed by a focus group (n = 7) of seniors along with other sources of information, suggested retention of such transferable skills, and, in some cases, deeper involvement in climate and sustainability action.

Keywords: climate change; learning community; interdisciplinary; systems-based design; environmental ethics; environmental science; community based learning; longitudinal research; case studies

1. Introduction

In recent years, as evidence of climate change impacts mounts [1,2] and the international call to find meaningful solutions to the global climate crisis intensifies, the educational community has sought ways in which to enhance climate literacy amongst students and the general public. Though the reality of climate change has long been recognized by the vast majority of climate scientists as a critical issue facing society [3–5], the nature and severity of the problem have never been effectively communicated to the general public [6]. Beginning in the 1980s, climate scientists such as Jim Hansen [7] and politicians such as then Senator Al Gore [8] thought that climate change data, if compellingly presented, would change minds on the issue and lead to effective action. Instead, after an initial period of growing acceptance, climate change literacy and the number of Americans believing that climate change is a very serious problem have remained quite low [9,10]. Furthermore, the increasingly partisan nature

of the issue [11,12] has continued to complicate the movement towards climate change acceptance for many Americans ([13] and the references therein). Interestingly, though the climate change attitudes and beliefs amongst undergraduate groups have been historically under-sampled [14], it is believed that this group (while still exhibiting the same partisan divide seen in other age brackets [15]) may be slightly more accepting of the reality of climate change than older members of society [14]. Regardless, it is clear that, as the physical and psychological [16] impacts of climate change continue to mount for populations around the world, the ways in which the climate change reality is communicated need reimagining.

Climate change skepticism or outright denial has been shown to be deeply rooted and incredibly hard to change: an individual's views are often inextricably linked to their personal identity and their perceptions of the ideas and beliefs of their peers [13]. Importantly, research suggests four-year residential colleges serving traditional age undergraduates are one context in which student attitudes may shift in a way that lasts [17,18]. Essentially, since many students undergo a re-envisioning of their identity during their undergraduate years, these students may be more likely to alter their views on an issue tied to their identity, e.g., their beliefs in the reality of climate change. This possibility creates an incredible opportunity for educators at those institutions to contribute to a lasting shift in a student's attitudes about climate change that extends well beyond their time in the classroom. Additionally, research has demonstrated that impactful curricula surrounding sustainability (particularly when supported by broad engagement within the community) has the power to create cultural shifts within families [19], the student body and within the community at large [20], further extending the potential impact of effective climate change education.

As the need for more effective climate change education has become obvious, educators have worked to design curricula that can both increase climate literacy and empower students to move towards more sustainable behaviors in their lives. A wide variety of research has demonstrated that this desired increase in climate literacy requires that educators identify their own climate change misconceptions [21], recognize the need to empower students towards action (rather than aiming to simply "increase awareness") [22,23], and understand the complexities of motivating students to overcome the many barriers they may face in accepting the reality of climate change [13,24]. The most effective of these educators are those that have moved beyond the traditional presentation of scientific theories and facts and instead have provided students with a conceptual understanding of the "big picture" and the impacts of individual actions [25]. Some successful strategies that have been utilized to date have included incorporating the ethical issues inherent in many environmental problems along with short-term immersive travel in threatened ecosystems [26], designing classroom activities that highlight the connection between individual actions (such as energy use) and climate change [27], focusing on interactive place-based pedagogy [26,28] and linking climate change impacts with human health [29].

The present curriculum can be considered an implementation of Reiter et al.'s [30] Sustainable Human and Environmental Systems (SHES) approach to education. Such an approach prioritizes "big picture" thinking and helps students gain a deeper understanding of the complexity of the environmental issues. As outlined by Reiter et al. [30], the five elements of SHES are: a systematic approach to learning; systems thinking; revealing complexity; holism; and supradisciplinarity. In the curriculum studied here, the systematic approach to learning included problem-based learning, including case studies, and community-based learning. Systems thinking was informally introduced to the students when examining the complex human-nature relations involved in cases of climate change causes and impacts. A holistic rather than reductionist approach to understanding and addressing environmental concerns was also introduced and utilized during the semester. Finally, though truly supradisciplinary education is constrained by institutional barriers, the curriculum examined here was strongly interdisciplinary. Rieter et al. [30] also identified 12 skills, 15 knowledge areas, and one experience that are crucial to effective environmental programs. From that list, the sophomore-year curriculum discussed in this paper focused most heavily upon: building student skills of collaboration,

communication, and problem-solving; and, student learning of the structure and function of biotic and abiotic systems, and environmental ethics. Most critically, this curriculum provided an extensive, semester-long, complex, holistic experience in which students applied skills and knowledge to environmental problem solving in the real-world. Though the three-course curriculum presented in this work does not attempt to address all the skills and knowledge outcomes Reiter et al. identifies, the Environmental Sciences and Studies (ENV) Program which houses the curriculum includes many more elements of the SHES approach. Prior to describing the specifics of the curriculum design, we first offer an overview of the school and programs in which the course resides (ENV program and the Cornerstone General Education Program), as this context provided the opportunities and the challenges of creating an effective curriculum.

Stonehill College is a small (2500 students) undergraduate-only, traditional age and predominantly residential institution located south of Boston, MA. As with many undergraduate environmental programs [31], the Environmental Sciences and Studies Program at Stonehill is fairly recent, with its first official graduate in 2008. However, in the past decade the program has undergone both rapid growth (leaving the program resource constrained by both the small number of faculty and an inadequate budget) and program revisions that have substantially altered the courses offered and the outcomes expected of our graduates. Today, two degree options are offered: a Bachelor of Science (BS) in Environmental Science, which predominantly follows Vincent and Focht's "Systems Science" curriculum model [32], and a Bachelor of Arts (BA) in Environmental Studies, which incorporates elements of both Vincent and Focht's "Adaptive Management" curriculum model and their "Policy and Governance" model [32]. The degree requirements for the BS and the BA degrees are shown together in Appendix A. As of May 2017, 51 ENV majors are working towards their degrees at Stonehill; the program has become the 11th largest (of 29) amongst the arts and sciences.

In redesigning the majors, the faculty sought to provide students with as comprehensive and interdisciplinary a curriculum as possible, thereby preparing them to tackle messy, complicated environmental problems in the real world. The goal was to address the problem Reiter et al. [30] described eloquently in their recent work: " ... neither stewardship of the natural environment nor long-term improvement of the human condition can be achieved without a holistic, integrated synthesis of disciplines aimed at managing the interaction of both human and ecological systems at their interface". The desired recognition of the complexity of environmental systems that would result from such a program is also identified within Wiek's [33] key competencies in sustainability as a "systems thinking competence". This competence requires that students be able to consider environmental problems across multiple scales and domains while also being able to understand how people and social systems (and their associated values, preferences, actions, etc.) relate to the overall problem. Vega-Marcote et al. [34] remind us as well that in our teaching, "It is not enough to acquire concepts; it is necessary to learn to put them into action, integrate them and use them adequately under different real-life circumstances." In other words, there is recognition within the environmental field that it is critical to teach students about environmental problems in such a way that they can use multiple lenses to gain a deep appreciation for the many factors at play in the real world. Mere transmission of content to the students would fall well short of this expectation.

One of the major learning outcomes of the redesigned ENV program prioritizes interdisciplinary thinking; it states that graduates of the program should acquire "the ability to integrate knowledge across disciplines, becoming skilled in the use of multiple lenses to analyze complexity." To achieve this outcome, three integrative experiences were included in both majors: a one-credit course geared towards promoting environmental change on campus for first year students, a choice of several nine-credit environmental learning communities (LC, the foundations of which are described in [35]) in the sophomore year and a one-credit senior capstone seminar coupled with a three-credit senior capstone experience (taking the form of faculty-guided research or an internship). With this work, we focus specifically on just one of these integrated experiences: an LC entitled *The Ethics and Science of Climate Change*.

As with many LCs around the country [35], the intent of LCs at Stonehill is to foster interdisciplinary thinking by focusing on a particular complex problem using an active pedagogy that engages the students. There is no shortage of complex environmental issues that could provide a focus for an LC looking to strengthen student ability to think deeply and critically about the interconnected nature of environmental dilemmas. However, both the geographic location of Stonehill (located near Boston, a city determined to be experiencing higher than average sea level rise [36] and predicted to experience above average temperature increases [37] in the coming decades) and the timing of the course (one year after President Obama was re-elected, noting "the destructive power of a warming planet" in his victory speech) provided excellent opportunities to teach about climate change and its solutions to a broad student population in the general education program. Furthermore, the ENV faculty were eager to respond to both anecdotal evidence (later documented in [21]) that students' prior exposure to climate change education may have been misinformed or incomplete and to the evidence that even well-educated people often failed to alter their attitudes and behaviors to become part of the solution [38–42]. As such, in this study we aim to answer two primary research questions: (1) whether and to what extent *The Ethics and Science of Climate Change* contributed to shifts in student views on climate change; and (2) whether and to what extent such shifts were retained two years later.

2. Materials and Methods

2.1. The Curriculum

The curricular structure chosen for *The Ethics and Science of Climate Change* was a nine-credit LC in which three courses were taught by two professors: each professor involved taught one disciplinary course and the third course was co-taught as an integrative course employing community-based pedagogy in order to enhance student learning (as demonstrated in [26–29]). The two disciplinary courses were "Introduction to Environmental Science" and "Environmental Ethics". To ensure that students of all majors would enroll, this LC met three of the requirements of the College's general education program (natural scientific inquiry, moral inquiry and the sophomore LC). In addition to addressing natural science and philosophy extensively, the disciplinary courses also incorporated relevant concepts from economics, politics, history and social psychology. Both the science and ethics courses addressed climate change causes and impacts in detail.

The integrative course required students to educate groups in a local community about climate change with a view toward encouraging them to make carbon-reduction changes to their behaviors as individuals and as communities. In the design of the events, students were tasked with teaching the science of climate change accurately and effectively, connecting to each audience's likely values (based on research into their partner organizations), and motivating the audience members to take particular actions (personal and/or institutional). Students were prepared for this work in a number of ways beyond learning the content of the disciplinary courses: they participated in a community-build exercise in which opportunities for and constraints on societal improvement were explored; toured the neighboring city (where most of our community partners were based) focused on positive community action related to climate change (a brown field converted to a solar field, energy conservation efforts, etc.); discussed climate change with others reluctant to accept its reality (which allowed the students to experience the promise and the challenges of such interactions); reviewed documentaries focused on climate change; and participated in a workshop on persuasive communication.

The community partners that participated in the semester-long program were chosen through faculty networking. Faculty sought partners among institutions in our neighboring community whose leaders expressed interest on behalf of their members in learning more about climate change and what they could do to address it. Adult audiences were the focus, rather than children or youth, to keep the challenge at a similar level for each of our student teams. Each team of six students worked with two community partners; students worked in four teams with eight partners, total. The partners represented a wide range of community institutions: participants included two local banks, two houses of worship, two councils

of aging, teachers in one middle-school, and the city council. The extent of collaboration between students and partners varied from co-creation of the culminating event to more passive attendance at a primarily student-designed gathering. Attendance at the eight events summed to more than one hundred community members, and they offered overwhelmingly positive feedback to the students.

2.2. Research Methods

This research employed a mixed-methods (quantitative and qualitative) approach in order to capture as holistic and comprehensive a view as possible of the impacts of the curriculum. The study is a longitudinal one, following the same students over the course of slightly more than two and one-half years (September 2013–April 2016).

2.2.1. Survey Research

In order to examine the effects of the curriculum on attitudes and beliefs about climate change, a survey was administered three times over the course of two and one-half years to the group of students that participated in the LC. The survey (see Appendix B for full text of survey questions and response options) given to the students throughout the experience was a slightly modified version of the short version of the 2011 Yale Climate Change Communication Project Survey published on-line (accessed in June 2013 from http://climatecommunication.yale.edu). The questions in Yale's online survey were a subset of a more extensive survey conducted by the Yale Climate Change Communication Project examining America's beliefs and attitudes about climate change [43].

This survey is a valid, often-used, and recognized instrument for assessing public perceptions of climate change, designed for an item-by-item analysis (rather than a scale yielding an overall score based on multiple questions). Our revisions to the survey were minor: the brief introductory comment from the survey was removed, "climate change" was substituted for "global warming" in all questions ("climate change" was chosen as a more accurate descriptor of the effects of global warming at the level the average person could perceive) and two open response questions (Q6 and Q13) were added to the fifteen multiple choice questions in the survey (see Table 1 in Results Section).

The research protocol utilized in this work was reviewed and approved by the college Institutional Review Board (Protocol #2015-16-14). Paper surveys were administered before class began on the first day of the semester in late August 2013, and again upon completion of the semester in mid-December. Twenty-four students enrolled and 23 completed both pre and post surveys as sophomores. Students enrolled came from majors across the college: three environmental students, eight humanities majors (English, history, etc.), seven social science majors (political science, psychology, etc.), one business major and four biology majors enrolled. These students had self-selected to participate in *The Ethics and Science of Climate Change* LC; fifteen other LCs were offered in Fall, 2013. In the spring of 2016, the same 23 students were invited to complete the survey again, in an on-line format; 17 chose to do so. Although this conversion from a paper to an on-line format may have slightly impacted the results, it was the best way to access students as seniors whom we were no longer seeing in classes. The data we present here follow these 17 students across the study period.

Student responses to the 15 quantitative survey questions were converted to sequential numbers (decreasing in the direction of greater climate knowledge, certainty, concern and urgency). Each student's answer to each of the 15 questions was then compared over time using paired one-tailed t-tests. In other words, each student's response was compared to the response that they gave later for each individual question. Non-directional options, such as "I don't know" and "other" were not coded nor included in the statistical analysis, though they are illustrated on the histograms. Modified responses, which some students created on the paper survey, were also removed from the analysis. The entire set of p-values (n = 32), including the numeric analysis of the open-response questions, was corrected for false discovery rate (FDR). The FDR method used entailed ranking all the p-values from least to greatest, multiplying each rank order number by 0.05/32 to calculate adjusted alphas. The first p-value which exceeds its adjusted alpha is the dividing line into non-significance; in this case,

it was the *p*-value of 0.0319 (alpha = 0.027). This was the *p*-value found for the post-LC to senior paired t-test for Q13. The significance of only one other value was affected by the FDR calculation: post-LC to senior paired t-test for Q14. These are noted as such in Table 1.

The two open-response questions added to the survey were included to allow students to demonstrate both the extent and breadth of their scientific knowledge of the consequences of climate change ("In the space below, list as many climate change impacts as you can".) and their understanding of the barriers to climate action ("In the space below, list as many reasons as you can for why some people aren't taking climate change seriously".). The number of correct or relevant answers each student offered were compared over the time periods, and analyzed with paired t-tests. For the more qualitative analysis of these data, student answers were randomized then read independently by three researchers to discern elements for which codes were then created and discussed. Each researcher returned to the data and applied the codes (interrater reliability = 92.4%). Any differences in that analysis were discussed and resolved.

All survey questions, both quantitative and open-response, were compared across two time spans for each student: pre LC to post LC and post LC to senior year. Unfortunately, one question (Q3) was inadvertently left out of the senior survey, so the latter pairings only include 16 questions instead of the original 17. The senior year version of the survey also included nine supplemental questions (henceforth "supplemental questions", one open-response and seven quantitative), to assess detailed climate science knowledge and actions taken. As these could not be paired with sophomore answers, no statistical analysis was possible; these answers, however, are incorporated in the case studies and those questions, along with basic descriptive statistics, are included in Appendix E.

2.2.2. Focus Interview Methods

The seventeen seniors who answered the senior survey were invited to attend a follow-up conversation. Participation was encouraged by entry into a gift card raffle, with a 50% chance of winning a card. Seven students attended one focus group session.

The focus group session was designed as a follow-up to the survey, to yield a richer view of the student experience. Employing best practices in focus group interviewing [44] the session began with welcoming conversation, moderated by Mooney and Burkholder. Once everyone had settled in, one very open question was posed: "In what way(s) do you believe participating in *The Ethics and Science of Climate Change* LC has continued to affect you? Please share both positive and negative aspects". As the conversation flowed, clarifying questions were asked as needed to ensure that researchers fully understood the student response. When the initial conversation began to lag, the researchers asked specific questions about other aspects of the student experience. Examples of these questions include: which of the course activities they found most memorable and compelling, whether they were more aware of social justice issues, and whether they felt more inclined toward interdisciplinary thinking. The conversation lasted for approximately 90 min, with some students leaving and others arriving after around 60 min. The focus group session was recorded with non-intrusive audio recording to which all participants consented.

Three students were chosen from the focus group for case study analysis in order to illustrate student responses to the curriculum. In addition to exhibiting a wide range of outcomes, the three students selected were chosen for the completeness of their data: we have incorporated quotes from the students' final essays (reflecting on the LC experience during the sophomore year), and from the senior focus groups, as well as data from the senior year supplemental questions. This combination creates a fuller picture of the impact of the experience from the student perspective.

3. Results

3.1. Results of Quantitative Analysis of Survey Responses

As described in Section 2.2, students participating in *The Ethics and Science of Climate Change* LC were surveyed to assess their knowledge and attitudes about climate change three times during their

time at Stonehill: at the beginning and end of the LC semester, and again two years later prior to their graduation. These surveys of student knowledge incorporated 15 questions in which each student selected an answer from among the options presented that best represented their knowledge or attitude on a particular topic at that moment in time; the analysis of the shifts in quantity of correct/relevant answers to the two open-response questions (Q6 and Q13) are included here as well. Fifteen of the seventeen survey questions yielded statistically significant shifts toward greater climate literacy during the sophomore semester, and for fourteen of these literacy was retained in the senior year survey (indicated by a lack of significant change between the sophomore post-LC survey and the senior survey responses). The analysis of the subset of 17 students who participated throughout the study (the focus of this manuscript) mirrored the results of the sophomore-only dataset of 23 students. Over the sophomore year, the same 15 questions showed significant change and the same two questions were not significant. A false discovery rate analysis for multiple comparisons yielded an adjusted alpha of 0.027. Therefore, all comparisons with *p*-values equal to or less than 0.027 were found to describe statistically different responses from the students across the testing periods (e.g., pre- and post-tests or post-tests and tests as seniors (Table 1)). In addition to the tables, we present histograms of the class response to each question to illustrate the overall effect of the curriculum. Several of these histograms are used in the following sections, and all are included in Appendix C. Although the average and range of answers across the whole class was not subject to statistical analysis in this study design, we provide those descriptive statistics in Appendix D.

Table 1. Results of paired t-test analysis of change in individual student answers over time.

Question Number (with Brief Note on Question Focus)	Paired *t*-Test Results				
	Pre-LC to Post-LC (Soph)		n	Post-LC (Soph) to Senior	
	p-Value	X dif ± SE		*p*-Value	X dif ± SE
Q1. Happening?	**3.1023×10^{-5}**	−1.12 ± 0.21	17	0.0817	0.12 ± 0.08
Q2. Natural or human-caused?	**0.0207**	−0.23 ± 0.11	17	N.S.*	0.00 ± 0.00
Q3. Worried?	**2.5674×10^{-6}**	−1.00 ± 0.15	17	Question not asked senior year	
Q4. Personal Harm?	**0.0028**	−0.57 ± 0.17	14	0.3357	0.07 ± 0.16
Q5. When harm?	**0.0055**	−1.06 ± 0.37	17	0.3019	0.18 ± 0.31
Q6. List impacts.	**0.0016**	3.18 ± 0.51	17	0.0569	−1.18 ± 0.70
Q7. Harm future people?	**0.0205**	−0.25 ± 0.11	16	0.1666	0.06 ± 0.06
Q8. Thought about before?	**0.0020**	−0.82 ± 0.25	17	0.2711	−0.12 ± 0.19
Q9. How important to you?	**4.2494×10^{-5}**	−1.00 ± 0.19	17	0.2110	0.18 ± 0.21
Q10. Could change my mind?	**9.4512×10^{-6}**	−1.35 ± 0.23	17	0.1807	−0.23± 0.25
Q11. Friends share views?	**0.0184**	−0.59 ± 0.26	17	0.3415	−0.12 ± 0.28
Q12. Closest to your view?	0.2908	−0.07 ± 0.12	15	**4.6813×10^{-7}**	1.27 ± 0.15
Q13. Reasons why some don't . . .	**4.8892×10^{-6}**	1.76 ± 0.28	17	0.0319 (NS, FDR)	−1.06 ± 0.53
Q14. Should people do more?	**6.4016×10^{-6}**	−0.71 ± 0.11	17	0.0481 (NS, FDR)	0.29 ± 0.17
Q15. Boycott opposing corps?	**0.0028**	−1.18 ± 0.35	11	0.1894	−0.36 ± 0.43
Q16. Priority for federal gov?	**7.1628×10^{-4}**	−0.81 ± 0.20	16	0.2722	−0.12 ± 0.20
Q17. Should US act . . . ?	0.0941	−0.19 ± 0.14	16	0.0819	0.12 ± 0.08

Significant *p*-values are shown in bold. With the exception of Q12, the directionality of significant change is toward greater climate knowledge, certainty, concern, and urgency. The full text of each question (and response options) listed in Appendix B. The *p*-value for the second set of responses for Q2 (indicated by *) was not calculated because the data showed no change across the time period; students responded identically as post-LC sophomores and as seniors.

The two survey questions that yielded no significant shift towards climate literacy over the sophomore year are Q12 and Q17. The last of these questions (Q17) had little room for a shift, given that all but five students were already at the maximum literacy as the LC began. The unusual pattern of student response to Q12 (moving from no shift during the sophomore year to a significant shift between the sophomore and senior years) is addressed in the discussion (Section 4.2) along with several other analyses of student responses.

3.1.1. Shift in Student Knowledge Revealed by Quantitative Analysis

Despite national polls showing that the American public as a whole still struggles to accept the reality of climate change, our student population came into the course unanimous in the belief that the

climate was experiencing changes. This starting state likely resulted in part from the fact that younger generations tend to be more accepting of the reality of climate change than older generations [14] and in part because of the location of our course: since the student population of Stonehill is regional, most students in the class grew up in New England, a region of the country that has historically been linked to more favorable attitudes about climate change. However, student responses at the beginning of the LC curriculum did reveal discrepancies in the level of confidence that the students had in their response. As evident in Figure 1 (which is a panel from Appendix C), all LC students responded that the climate was changing, but only slightly more than 20% of the students declared that they were "Extremely Sure" about this assertion, with the same percentage also declaring they were only "Somewhat Sure". One student respondent even noted that they were "Not at All Sure" as they headed into the semester.

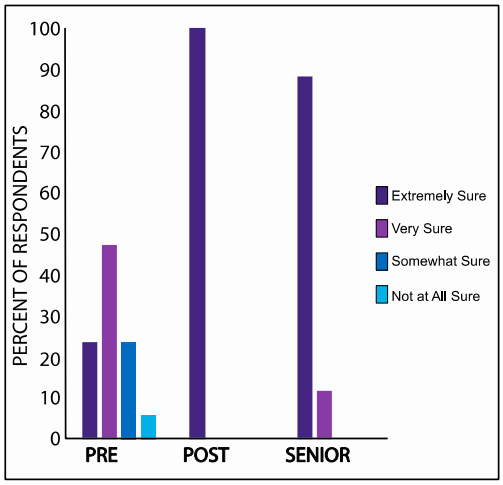

Figure 1. Q1. Is climate change occurring?

Encouragingly, by the end of the semester the students unanimously became more sure of their knowledge; they were "extremely sure" that climate change was occurring. This shift in student knowledge about the reality of climate change was a statistically significant one ($p = 3.1023 \times 10^{-5}$), and was supported by similar statistically significant shifts in student recognition that humans were responsible for the changes that are occurring in our climate (Q2; $p = 0.0207$) and that the impacts of climate change are already being felt (Q5; $p = 0.0055$). Perhaps even more importantly, the students were able to successfully retain this shift in their knowledge on Q1 (though two seniors did slightly "backslide" into responding that they were "very sure" rather than "extremely sure", there was no statistically significant shift in student views between the end of their time in the LC and their senior year).

3.1.2. Shift in Student Attitudes Revealed by Quantitative Analysis

One of the survey questions (Q9) that best represents shifts in student attitudes towards climate change asked students to assess how important the issue of climate change was to them personally. The initial responses of our student population to this inquiry suggested that most students in the class were lukewarm: they ranked the importance of the issue as only "somewhat important". This attitude may have been in part driven by their initial lack of confidence in their beliefs (Figure 1); if a student is not very sure that climate change is occurring in the first place, it may have been hard for that student to prioritize the issue in any way. Importantly, these attitudes also reflect the national trend in the US reported by Pew Research, which stated that only 45% of Americans believe that climate change is a very serious problem [9].

However, responses to this question at the end of the semester indicated that the students' attitude about the significance of the climate change issue in their own lives had been shifted (Q9;

$p = 4.2494 \times 10^{-5}$, Figure 2a); by the end of the semester 86% of the students rated climate change as an issue that was either "very" or "extremely" important to them. Additionally, the seniors surveyed retained this more positive attitude: they still considered climate change to be of great importance (the shift between the sophomore year post-LC survey and the senior year survey was insignificant). This shift towards personal prioritization of climate change was also mirrored by a shift in the students' belief that climate change should be a higher priority issue for our elected officials (Q16; $p = 7.1628 \times 10^{-4}$, Figure 2b), a shift which was also retained as the students approached graduation.

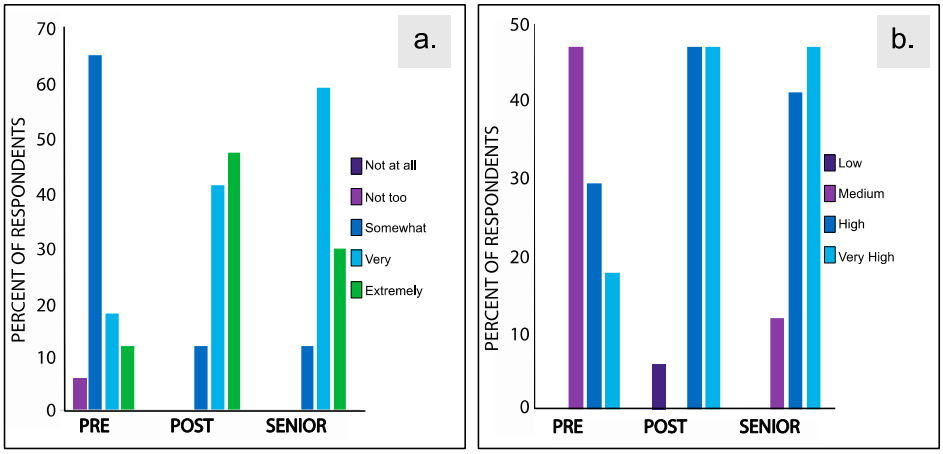

Figure 2. (**a**) Q9. How important is the issue of climate change to you personally? (**b**) Q16. Do you think that climate change should be a low, medium, high or very high priority for the President and Congress?

3.2. Open-Response Survey Questions Results

Though the results above shine light on the students' shifting knowledge and attitudes, much can also be gained by more closely examining their responses to less structured, more open-ended questions. Research has repeatedly shown that using qualitative techniques when researching can provide a level of richness that would otherwise be overlooked (for an overview, see [44]). Accordingly, we present the analysis of the students' responses to open-ended questions in the survey (also, in Section 3.3, we offer case studies of three students informed by a variety of qualitative data).

The first open-ended question from the survey asked: "In the space below, list as many climate change impacts as you can". The coded responses to this inquiry are shown below in Table 2.

Table 2. Coded responses to Q6. "In the space below, list as many climate change impacts as you can". Number of correct responses per student over time was subject to statistical testing, with bold values indicating significance (see Table 1 for *p*-values).

Q6 Analysis	Sophomore Year		Senior Year
	Pre	Post	
Number of Students Surveyed	17	17	17
Average Number of Correct Responses per Student	**4.06**	**7.47**	6.35
Total Number of Factually Incorrect Answers	15	5	9
Number of Students Citing:			
Rising Sea Level	5	15	15
Extreme Weather	4	13	14
Loss of Biodiversity	8	11	11
Detailed Ocean Effects	0	6	6
Detailed Atmospheric Effects	0	4	3
Human Health Impacts	4	8	3

As evident by the data in Table 2, students improved in their scientific knowledge of the impacts of climate change, and retained much of that knowledge two years later. Paired t-tests on the number of correct answers each student offered confirmed a significant increase ($p = 0.0016$) over the course of the sophomore LC, and suffered no significant loss of that knowledge in the senior year. A number of particular impacts listed by the students that reveal interesting patterns are also included in the table. The total number of incorrect answers from the class dropped from 15 to five over the course of the semester, and remained lowered, at nine, in the senior survey.

The second survey question asked: "In the space below, list as many reasons as you can for why some people aren't taking climate change seriously". The patterns revealed by coding the responses are displayed in Table 3. Student answers revealed a significant increase in the number of reasonable answers ($p = 4.8892 \times 10^{-6}$) over the sophomore curriculum which was retained as seniors, two years later. Common barriers identified by the students included psychological ones, including apathy, denial, diffusion of responsibility, inconvenience, fear, feeling powerless, mistrust, and the difficulty of habit change. In total, psychological barriers were cited 26 times pre-LC, 30 post-LC and 29 in the senior surveys. Many students also cited lack of first-hand experience and lack of education, while fewer mentioned the belief that climate change was natural or the belief that the issue was less important than other issues we face. Still fewer students cited the influence of social institutions.

Table 3. Coded responses to Q13. "In the space below, list as many reasons as you can for why some people aren't taking climate change seriously". Number of responses per student over time was subject to statistical testing, with bold values indicating significance (see Table 1 for *p*-values).

Q13 Analysis	Sophomore Year		Senior Year
	Pre	Post	
Number of Students Surveyed	17	17	17
Average Number of Pertinent Responses per Student	**3.47**	**5.29**	4
Number of Students Citing:			
Psychological Barriers	15	13	13
Lack of First Hand Experience	12	13	10
Lack of Education	6	10	8
Natural Changes	5	2	6
Politics	2	6	3
Less Important Than Other Issues	1	4	3
Norms/Traditions/Social Constraints	1	0	3
Costs Too Much	1	3	1
Religion	1	1	0
Scientists/Leaders Will Solve the Problem	0	2	0
Media	0	5	0
Corporations/Businesses	0	0	0

3.3. Case Studies

While some outcomes were common to all students in the focus group (for example, every student mentioned the value of the transferable skills they acquired in the Learning Community, such as public speaking), the degree to which students engaged beyond that acquisition of skills varied widely. In the sections that follow, we highlight one student (Janet) who reported little change beyond this, a second student (Sheila) who reported personal pro-environmental behavior along with encouraging others in her social sphere to do so, and a third student (Anne) who added an ENV major and reported a desire to create positive change on a broader scale.

To protect student privacy, the names of the highlighted students are pseudonyms rarely found among college students today.

3.3.1. Janet, Developing Transferable Skills

Janet, a business major, is representative of those students who learned the material of the LC well but did not respond to the need for personal change and political action in the face of that knowledge. However, despite her lack of motivation to alter her actions or way of life upon completion of the curriculum, Janet did greatly improve and retain a variety of transferable skills. This outcome, though it falls short of the aim of the LC, is still an important outcome for any college curriculum (particularly one housed within the General Education Program).

In the self-reflection portion of the final LC essay her sophomore year, Janet focused on transferable skills such as public speaking:

> *I have always been a shy person in new situations so I was never one to volunteer to speak at large events but in this situation we were forced to. I was forced to make an effective PowerPoint and not use notecards therefore I had to completely understand my topic. In the past during presentations I memorized a speech, and recited it to my peers but during the public presentations, I had an idea of what I needed to say and then just spoke. This allowed me to relate to my audience better and some things I said just because they came to the top of my head. These presentations made presenting for me seem like more of a conversation rather than memorized speech. I learned one of the most important things is to read the audiences' facial expressions and react to them.*

Clearly, Janet learned that public speaking is not merely a matter of speaking clearly at an audience but becoming an expert on the content and relating to the people in front of you.

Janet also noted improvement in her collaboration and leadership skills:

> *I never believed in my ability to work in a group setting to achieve a goal. I have worked on small group projects in the past but never one to this extent. This experience I found invaluable because although I felt overwhelmed throughout the semester, it was very similar to the working world. We worked with a team for a long period of time and had to pick up each other's slack and rely on each other to succeed. I never saw myself as a team leader before this project, but it gave me to opportunity to lead my peers yet not become an overwhelming controller.*

The course project was designed to be challenging enough that student teams would have to work well together over the long term (two to three months) to succeed. Janet's comment above indicates that this structure led her to develop a view of teamwork and the skills required to succeed in it that she lacked prior to the experience.

During the senior focus group interview, Janet also recalled two other lasting impacts from her participation in the LC:

> *One is that with everything that's been happening [warm winter], I felt like if I didn't take the LC, I would have been completely oblivious . . . With everything going on and the [climate change denial] posts on Facebook I felt like I knew more, knew what was going on . . . . I understood that the warming is affecting our whole climate more than I would have if I hadn't taken it.*
>
> *From the presentation side . . . Now (with an upcoming presentation to the board of directors at [another corporation]) having that experience as a sophomore helped me so much- I'm not nervous at all to go to them. I learned so much presenting-wise, I think that was the best thing I took overall from the whole LC. The huge thing was getting off campus and doing it to not peers . . . everyone is freaking out because we're going somewhere else, but I've already went to the [community partner] and been off campus.*

Janet's comment about social media posts indicates that she developed and retained some level of knowledge about climate change and the critical thinking skills to resist misinformation and manipulation. It is interesting to note that Janet does not mention replying to the posts; she uses the skills and knowledge to navigate her world better, but does not attempt to influence others. Janet then

returns to the theme of public speaking, noting that the sophomore curriculum left her emotionally well-prepared for one challenge of her senior year as a business major, presenting to a corporate board.

On the supplemental questions, Janet noted that the Climate Change LC contributed somewhat to her continued interest in the issue of climate change (6 on a scale of 10). Furthermore, when questioned about action steps, Janet reported that a motivation to decrease her carbon footprint did not inform her choice of meals, nor of transportation. That motivation also did not lead her to contact political leaders or take direct political action herself over the last six months. She did note, however, that carbon reduction motivated her to decrease her electricity use twice in the last week, and to read climate change news three times in the last six months. Janet simply noted "Public speaking" in the one question which was open-response in the supplemental section of the senior survey ("beyond climate change literacy, in what other ways do you think the LC experience influenced you?")

In sum, Janet's case represents students who learned a variety of transferable skills, but who barely changed their lifestyle in order to decrease their carbon footprint. This failure to act according to the knowledge one possesses is a common response to the cognitive dissonance that climate change literacy induces [13].

3.3.2. Sheila, Personal Change Extended to Family

Sheila had much in common with Janet, and many of the students, at the start of the curriculum. She arrived in the LC with little background or comfort in the study of science, ethics or climate change. However, though she was incredulous when first presented with the scope of the community project as a sophomore, she was proud of her personal and team-wide success upon completion. As a senior, Sheila commented "*It's so cool to reflect now back on something that you thought you would never be able to do.*" Like Janet, she cited the value of the transferable skills, especially public speaking and collaboration, in both her sophomore reflective essay and in the senior focus group. However, Sheila reported a greater degree of personal behavior change and more engagement with changing others within her social sphere than Janet reported.

For example, in the focus group, Sheila reported that she shared her learning in the LC with her family in a number of ways:

> *After that class . . . I was talking to [my Mom] about how corn is in everything.... She literally re-evaluated her pet food decisions- she asked me "Sheila, do you know that this entire pet food is all corn?" and I said "I know Mom, I told you, it's in everything . . . " so now she gives them organic, real food. And now my Mom has completely changed the way that WE eat . . . not just the dogs . . . she's "no corn anywhere, ever" now . . . . This LC definitely affected my family.*

and

> *I'm still really annoying with my family if I go home, especially with water. I was never so conscientious about water- the Ogallala Aquifer has taken over my mind. We'll be at the dinner table and my Dad will start washing dishes and he'll have the water running and I'll be sitting there like this (taps fingers . . . "turn the water off" . . . taps fingers). My family has made it into a joke now- if the water is running for more than 30 s, they'll all start laughing and go "Ogallala Aquifer!" and I'm like "It's going to run out in 25 years, OK?"*

As these two examples illustrate, Sheila brought much of the science and ethics of climate change back to her home. She reports change in her family's choices regarding the industrial food system, and water conservation as an area of ongoing work, reaffirming Uzzell's [19] assertion that children (and schools) can act as agents of change by educating parents to embrace more environmentally sustainable behavior.

Sheila also reports how the LC helps her discuss climate change with family members who reject it, though she accepts the low odds of changing such minds:

> *I've been able to talk to my aunt- I don't think she's changed her mind about it at all, but I feel like I've been able to actually talk to her and offer . . . . Even since then, even since the LC. I wish I could change her completely, but obviously you can't with some people.*

In addition, Sheila has taken her interest beyond her family, and her ethnicity and nationality, as well:

> *I work at [a restaurant] ... One of the girls was talking about how her village in China . . . it was one of the days that we got a lot of snow . . . and she was like "My village hasn't seen snow in over 100 years, but we used to". And I'm like "Wow! Tell me more! Tell me more about the climate of your small village in China". Obviously she has talked about the carbon dioxide- how their emissions are so bad. And I kept thinking "This is really interesting, I want to talk to you". I was more interested in that than I would have been if I hadn't taken the LC.*

On the supplemental questions of the senior survey, Sheila noted that the Climate Change LC contributed very highly to her continued interest in the issue (10 on a scale of 10). As for action steps, Sheila indicated more commitment to personal action rather than action at the political level. She reported that a motivation to decrease her carbon footprint informed her choice of four meals in the last week, and led her to decrease her electricity use ten times. Three times in the last month she reported that concern for climate change influenced her choice of transportation and led her to read climate change news seven times in the last six months. However, she reported just once in the last six months contacting a leader on the issue and just once taking more direct political action such as signing a petition or attending a rally. Sheila highlighted her commitment to personal behavior change in the open-response question at the end of the supplemental questions that the LC "*made me aware of the small changes I can make in my daily routine in order to reduce my carbon footprint.*"

In summary, Sheila developed and retained knowledge along with concern about climate change and related environmental problems. This led her to shift her own behavior toward greater sustainability and to engage with those around her on this topic. Furthermore, she was motivated to learn more and to encourage others toward pro-environmental actions. However, Sheila did not report attempting to create change in the society beyond her close associates.

3.3.3. Anne, a Desire to Change the World

Anne, a communication major, also valued the transferable skills gained in the LC. Like Sheila, Anne reported changing her own behavior to decrease her carbon footprint in a variety of ways. However, Anne presents another response to the curriculum: a desire and sense of agency to bring about change in the world.

In the self-reflection portion of the final LC essay her sophomore year, Anne noted:

> *I learned that I have the power to influence and spark change. When initially given the task of being the experts on climate change to a room full of adult strangers, I did not think that anything that I would eventually say to them would make a difference. However, after gaining all the necessary knowledge and doing my research I felt a little more confident. After presenting . . . I really saw the difference I was able to make, though small, in these people's lives. Influence doesn't have to come only from those in positions of higher power, anybody with enough credibility and drive for a change can influence those around them. This is something really important that I think everyone should learn about themselves. . . . Often times we don't even try to make a difference because we feel that it will be for nothing. But, if we put in enough effort, change, even small, can be made.*

Such a sense of agency among young people is crucial to promoting the necessary societal changes to avoid the worst of climate change. Like Sheila, Anne's reflections, and actions, offer a glimmer of hope.

During the focus group interview senior year, Anne identified several other areas in which the LC influenced her: she added a major in Environmental Studies to gain more knowledge and skills;

she developed an appreciation for the many perspectives people bring to an issue; and she began to think in a more interdisciplinary way. All three of these set her up well to grow as an agent of change.

> *The big change was that I added environmental studies to my other major.*
>
> *[The LC] really taught me critical thinking skills- that's really what I got out of it. Looking at things from different perspectives (we had to go to an elementary school and a senior citizen center [for their end of semester presentation]), so we had to think of things from different points of view. That's what I really got out of it other than presenting- thinking about things in a different way and trying to talk to people from their point of view . . . that's really been helpful.*
>
> *I notice more how all of my courses are connected . . . . Sometimes we'll be talking about something in one class and it will go to the others. It's really cool to see how they all work together, and I guess the LC was the first time that I took integrated things like that. Now I notice more how I can apply different things to different areas.*

On the supplemental questions, Anne noted that the LC contributed very highly to her continued interest in the issue of climate change (9 on a scale of 10). Additionally, Anne reported that a motivation to decrease her carbon footprint informed her choice of two meals in the last week, and led her to decrease her electricity use seven times. Four times in the last month she reported that climate concern influenced her choice of transportation, and led her to read climate change news more than ten times (the maximum option) in the last six months. She reported taking direct action such as signing a petition or attending a rally four times; however, she never contacted a political leader to ask for action. The step into political action and activism remains a daunting one for many of our traditional age undergraduates [45]. However, as Anne noted in the open-response question, *"The LC . . . made me more conscious of my lifestyle choices and their impact on the environment and it influenced me to stay up to date on the current climate change issues and news in the world."* Anne's commitment to staying informed may be an intermediate step to becoming more politically active at some point in the future.

In summary, Anne represents students who felt a burgeoning sense of agency from the experiences of this curriculum. We believe that working effectively with a team to promote climate knowledge and action in the broader community played a role in creating such a sense of agency. Of course, this sense could be temporary, especially if this is not followed by reinforcing experiences and if social forces push back against such newly developing attitudes.

4. Discussion

As described in Section 1, the goals of the *Ethics and Science of Climate Change* went beyond merely teaching the students facts about climate change. Rather, our goals were to design a curriculum that taught the students in such a way that they exhibited shifts in both knowledge and attitudes and that created lasting change in those knowledge and attitudes two years later. Here, we use the various pieces of evidence detailed in Section 3 to determine whether and to what extent we met those goals, as well as exploring factors which most likely contributed to those outcomes.

4.1. Sustained Improvements in Climate Literacy

As evident in Table 1, student knowledge and attitudes shifted during the Learning Community; students shifted towards greater climate knowledge, certainty, concern and urgency for 15 of the 17 survey questions over the course of the sophomore semester. Furthermore, the data indicate that the increases in climate literacy were retained for the two years following the end of the curriculum: with only one exception (analyzed further in Section 4.2) there was no significant loss of climate literacy between the sophomore and senior years. The qualitative analysis further supported the conclusion that students underwent a shift towards greater climate literacy that persisted beyond the end of the curriculum. It is likely the curriculum was a contributing factor in producing these strong and persistent shifts. Therefore, considering which aspects of the curriculum design, pedagogy and context

were most important in this outcome is of interest. Unfortunately, separating the influence of the curriculum from the influence of outside forces that acted on our students across their time with us is not possible without a control group. However, here we consider, based on the previously published literature, some of the likely reasons that our students were positively influenced.

4.1.1. Curriculum Design and Pedagogy

As detailed in Section 1, more and more research indicates that improving student climate literacy requires that educators move beyond the traditional teaching methods. Furthermore, we know that the integrative, in-depth examination of topics inherent in the Learning Community structure [35] can provide particularly valuable learning experiences. As such, the Ethics and Science of Climate Change was designed following a systems approach in order to foster a deeper understanding of the complex structure of environmental problems such as climate change and the associated societal inaction in responding effectively to it [33]. The interdisciplinary structure of the LC, linking ethics and natural science as well as incorporating elements from the social sciences, likely influenced the students' ability and inclination to view the complexities of climate change through various lenses; see, for example, Anne's comments about this.

By employing community-based learning, we aimed to foster connections with the community beyond campus as well as empower our students to take effective personal and political action to address the problem. This desire to empower students towards action (rather than merely "increasing awareness" of the problem) has been previously linked to enhanced outcomes amongst students [22,23]. Some positive outcomes that could potentially be attributed to this "empowerment" style of instruction were described by the case-study students Anne and Sheila: they described personal behavior change (both Sheila and Anne), attempts to influence others toward such pro-environmental behaviors (especially Sheila), and seeking out additional related knowledge (in an academic context (Anne) and/or social context (Sheila) and/or from the media (both Sheila and Anne)).

By incorporating public presentations in the LC, students may have reached a deeper level of understanding of the complexities of the material than if the course had been taught with traditional pedagogical techniques. In preparing their presentations to the community, students were challenged to understand the complexities of climate change as a scientific and social problem well enough to teach it, twice, to two different audiences. In the design of their presentations, students had to consider the likely concerns and viewpoints of each audience, and lead the audience to see the ethical dimension of climate change as well as the scientific. Students also had to offer practical steps the audience members (and/or institution of which they were a part) could take to decrease their carbon footprints.

At least two strategies employed in our teaching, and adopted with modification by the students in their teaching of the public, were likely contributors to the outcomes we document in this research: we explicitly addressed student misconceptions about climate change [46] and we closed the distance they felt from the impacts of climate change [13]. For example, students often come to college confused about the causes of climate change. Plutzer et al [21] reported that 31% of middle school science and high school biology teachers explicitly send contradictory messages regarding the causes of climate change: they teach students that both anthropogenic and natural causes may be responsible for the observed changes to our climate. The instructors explicitly addressed this and other misconceptions about climate change as discussed in the public sphere. For example, the students examined the "natural cycles" of carbon dioxide levels in the atmosphere and compared those to the modern day atmospheric concentrations. This explicit tackling of such common sources of confusion may have helped to dispel misconceptions that the students possessed prior to the curriculum. Such misconceptions interfere with conceptual learning [46]. The experience of considering which misconceptions might be common in their audiences and how best to dispel them in their presentations likely enhanced the students' conceptual understanding of climate change.

A second barrier to climate change acceptance which we addressed in our teaching, and the students addressed in their public presentations, is the feeling of distance (in both time and space)

between oneself and the impacts of climate change ("It's not hitting me, my family, or my pack group (yet) ([13], p. 29)"). The LC students recognized this issue: when asked, they identified lack of firsthand experience as a barrier to climate action (Table 3). However, by discussing the local and immediate impacts of climate change (i.e., sea level rise impacts on Boston and/or the potential link between extreme weather events already being experienced and climate change), the instructors may have reduced this barrier and left students with a better sense of how climate change would directly impact their lives. The students, in turn, incorporated such local details into their public presentations, which most likely solidified their knowledge of them. The analysis of the open-response questions (both as sophomores and as seniors) indicates that many of these facts that were directly related to our students' lives resonated with them: the impacts of rising sea levels and extreme weather both appeared in more student answers after the curriculum than during the initial survey (Table 2).

4.1.2. Context: Opportunity for Lasting Change

Finally, it must be acknowledged that our students' age and residency at a four year institution may have played a role in the success of the curriculum in creating lasting change in student knowledge and attitudes. As highlighted in Alwin et al.'s fifty-year longitudinal study of Bennington women [18], exposure to new knowledge, attitudes and belief systems during this impressionable period in a student's life may create lasting shifts in student attitudes for years to come. In the case of the Bennington women, many of the attitude shifts that they experienced as undergraduates appear to have been permanent: they maintained their altered opinions as many as 50 years after completion of their undergraduate degrees. It would be interesting to study whether the increased environmental awareness and concern that the LC students seem to have gained during their time with us proves to have such staying-power.

4.2. Areas Targeted for Growth

Unfortunately, when students were queried as sophomores about their optimism that humans had both the ability and will to make the changes necessary in order to lessen the impacts of climate change, the students showed no significant shift in their thinking. Furthermore, when they were surveyed as seniors, the students showed a significant ($p = 4.6813 \times 10^{-7}$) slide towards pessimism (Q12, Figure 3). In their responses to Q12 (Figure 3), when asked which statement they believed described our societal response to climate change, the students began the semester with a fairly optimistic perspective: 76% of them felt that humans had the ability to reduce the impacts of climate change, though it was unclear whether or not they would do so. However, two years after the semester ended, not a single student responded with that level of optimism. Instead, 59% of the students responded as seniors that "Humans could reduce climate change, but people aren't willing to change their behavior, so we're not going to" and the other 41% became even more pessimistic, answering that "Humans can't reduce climate change, even if it is happening". The increased pessimism of the students may have been the result of a heightened awareness of the small amount of progress that was made towards emissions reductions goals between the time that they completed the curriculum and the end of their senior year. As pointed out by Doherty and Clayton [16], the indirect psychological impacts of climate change on members of society (based on factors including the uncertainty regarding future risks) can take a very real emotional toll, which may have contributed to the increased pessimism of our students. However, this finding also highlights the need to provide the students with more meaningful ways to become a part of the solution. Stoknes [13] describes the state of "cognitive dissonance" that students can find themselves in: if students are made aware of the dangers of climate change but then are not given meaningful ways to become a real part of the solution, a lack of hope can set in, leading to pessimism regarding the outcomes of climate change action and even a psychologically-defensive rejection of climate change.

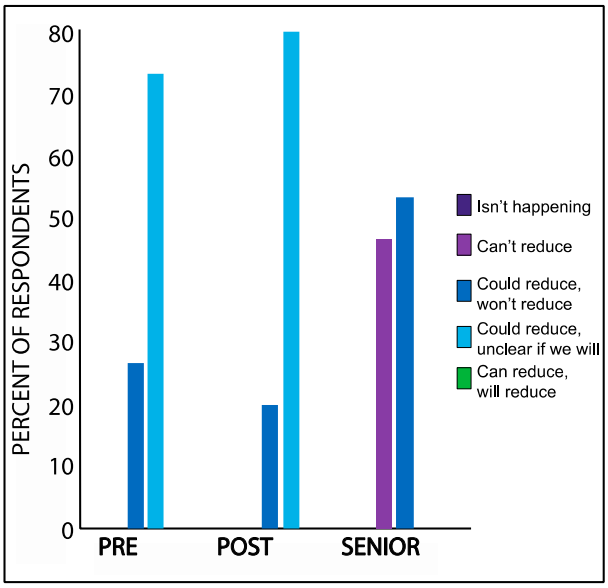

Figure 3. Q12. Which of the following statements about climate change comes closest to your view?

Certainly, this slide may have reflected the cultural background sentiment at the time: in the Fall of 2013 when the students were enrolled in the LC, the Obama administration was pursuing climate change strategies with some success, including a well-publicized strengthening of the Corporate Average Fuel Economy Standards. However, by the time the students were resurveyed during the Spring of 2016, the country had undergone a number of less-than-optimistic moments, including the full arrival of the presidential primary season (which included many candidates who openly rejected the reality of climate change) and the stay issued by the Supreme Court in February, 2016 which cast doubt over whether the Obama Administration's Clean Power Plan would be fully enacted. Though the events of the world may have played a role in the increased pessimism of the students, this result highlighted the need to revise our curriculum in order to help our students develop resiliency.

4.3. Limitations of the Current Study

Certainly, the current study had limitations. For example, our study cannot be considered to be representative of the "average" undergraduate student: by focusing exclusively on Stonehill students, who come primarily from New England, we may have introduced a regional-bias into our data. Furthermore, since Stonehill students self-select their own LC based on their personal interests, our students may have been more likely to shift their attitudes than students who chose other LCs. Our analysis was also constrained by the self-reported nature of the data; however, to discern such internal states as beliefs and attitudes, self-report is required. Finally, the robustness of our analysis was limited in this first iteration of the LC by a small sample size and by the lack of a control group.

4.4. The Future of The Ethics and Science of Climate Change

Our research into the successes and shortcomings of the LC led to substantial changes in subsequent iterations in both content and structure. The student responses to the open-ended questions were particularly helpful in identifying areas for improvement. For example, given that human health effects are commonly considered gateways to concern over environmental threats, even to the point of crossing the political aisles, we were surprised to see that few students mentioned health impacts after participating in the LC. As evident in Table 2, few of the students cited them initially, and though that increased as sophomores, the number citing health impacts returned to a value lower than the starting point by the senior year. Currently, the lack of connection the students made to human health represents a missed opportunity. As pointed out by George and Brenner [29] science projects that

relate to people's health and well-being are particularly successful in promoting student involvement and learning, particularly with female students. We aim to better incorporate the link between climate change and human health in future iterations of the course. Another opportunity these responses reveal is that future iterations of the curriculum ought to address the role of social institutions in contributing to climate change, as so few students reported recognizing these as barriers to climate action.

Beginning with the class of 2018, the curriculum was also revised to include more extended and collaborative interactions with the communities beyond our campus: teams of students now serve as consultants to community organizations seeking to decrease their carbon footprint. We expect this revision to better empower students and build resiliency as students work with supportive community partners to propose and take specific actions. The confirmation of seeing one's work come to fruition in the community may serve to insulate their growing sense of agency from social forces against climate change action. Beginning with the class of 2019, a greater focus on the psychology of climate literacy and action was added, equipping the students with a comprehensive understanding of the barriers and opportunities they will encounter in themselves and when working with the community.

Finally, in order to achieve a more comprehensive assessment of the impacts of the experience, the supplemental questions asked of the seniors in 2016, which inquired about the extent of personal and political action to address climate change, have been made permanent; they will be included in all future surveys. This will allow us some indication of whether and to what extent the learning fosters action. In addition, we have drawn a control group from students in other non-environmental LCs offered the same year, with particular success recruiting controls in the class of 2019. In this way, we will control for any changes in the campus climate literacy overall.

5. Conclusions

In this work, we analyze the efficacy of a learning community curriculum entitled *The Ethics and Science of Climate Change* in creating meaningful, long-lasting learning in a group of sophomore undergraduates. The students enrolled in two disciplinary courses which introduced them to both the science behind climate change and to the ethical dilemmas that it creates, and co-enrolled in an integrative course in which they designed and led educational presentations about climate change for a variety of community groups in the area. Our analysis indicates that the curriculum: (1) altered student knowledge and attitudes during the semester that it was offered; and (2) created shifts in knowledge and attitudes that were retained two years after the curriculum ended. The curriculum also appears to have enhanced students' transferrable skills (public speaking, etc.).

The Stonehill College mission calls upon the faculty to "educate the whole person so that each graduate thinks, acts, and leads with courage toward the creation of a more just and compassionate world". Like many environmentalists, we see climate change as a barrier to achieving such a world, and seek to create opportunities for students to "think, act and lead" on climate change action. Furthermore, we recognize that much of the work that needs doing to address this and other environmental problems will not be done by environmental professionals. Such complex problems require the active participation of people in all career paths. Thus, we sought to design a powerful and memorable learning experience in which students of all majors develop the climate literacy that will enable them to contribute to addressing the complex issue of climate change.

At this critical moment in history, as we try to alter our present course towards a more stable climate future, it is critical that we act to educate others about the causes, consequences and solutions to climate change. We will continue to revise, teach and study this curriculum, and hope that others will find our work of use in their own efforts to create a more just and sustainable world.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. The BS and the BA Environmental Major Requirements.

Required Courses Common to both BS and BA	
Biological Principles II Ecology Principles of Environmental Science Environmental Geology Geographic Information Systems One environmental Learning Community integrative seminar Senior seminar, and Senior Capstone: Internship or Research or Senior Thesis	
BS in Environmental Science (Total 64–67 Credits)	**BA in Environmental Studies (Total 41 Credits)**
Additional required science/math courses: Biological principles I Calculus I Organic Chemistry I General Chemistry I Environmental Science Research Methods Climate Science Statistics for Science	
Plus choice of THREE from this list: Environmental Botany **OR** Marine Ecosystems Microbiology Vertebrate Physiology Evolution Wetlands Ornithology Adaptations to the Environment Organic Chemistry II General Chemistry II **OR** Inorganic Chemistry Analytical Chemistry Sustainable Agriculture Introduction to Oceanography Topics in Environmental Science	*Choose FIVE of the following:* Environmental Economics Environmental Ethics Environmental Law Water Resource Management **OR** Coastal Zone Management Sustainable Agriculture Topics in Environmental Studies Environmental Policy and Politics Environmental Justice Contemporary Global Issues EcoSpirituality Justice, Peace and Ecology Buddhism, Nature and Environmental Ethics Environmental Sociology Community Organizing The Nature of Art
Plus ONE from this list (Humanities): Environmental Ethics The Nature of Art EcoSpirituality Justice, Peace and Ecology Buddhism, Nature and Environmental Ethics	
Plus ONE from this list (Social Sciences): Environmental Economics Environmental Law Water Resource Management **OR** Coastal Zone Management Environmental Policy and Politics Contemporary Global Issues Environmental Sociology Community Organizing	

Appendix B. Complete Text of Survey Questions and Answer Options

Answers were coded in direction of greater climate knowledge, certainty, concern, and urgency (in order as listed below; others, reverse coded (*)). "Other" and "I don't know" answers, which would

confound the directional analysis, were not coded nor included in the statistics, but are included in the grouped data illustrated with histograms (Appendix C).

- Q1. What do you think? Do you think that climate change is happening?

  YES . . . and I'm *extremely* sure . . . and I'm *very* sure . . . and I'm *somewhat* sure . . . but I'm *not at all* sure

  NO . . . but I'm *not at all* sure . . . and I'm *somewhat* sure . . . and I'm *very* sure . . . and I'm *extremely* sure

  OR I don't know
- Q2. Assuming climate change is happening, do you think it is . . .

  Caused mostly by human activities

  Caused mostly by natural changes in the environment

  Other

  None of the above because climate change isn't happening
- Q3. How worried are you about climate change?

  Very worried

  Somewhat worried

  Not very worried

  Not at all worried
- Q4. How much do you think climate change will harm you personally? *

  Not at all

  Only a little

  A moderate amount

  A great deal

  I don't know
- Q5. When do you think climate change will start to harm people?

  They are being harmed now

  In 10 years

  In 25 years

  In 50 years

  In 100 years

  Never
- Q6. In the space below, list as many climate change impacts as you can.
- Q7. How much do you think climate change will harm future generations of people? *

  Not at all

  Only a little

  A moderate amount

  A great deal

I don't know

- Q8. How much had you thought about climate change before today? *

  Not at all

  A little

  Some

  A lot
- Q9. How important is the issue of climate change to you personally? *

  Not at all important

  Not too important

  Somewhat important

  Very important

  Extremely important
- Q10. How much do you agree or disagree with the following statement: "I could easily change my mind about climate change."

  Strongly disagree

  Somewhat disagree

  Somewhat agree

  Strongly agree
- Q11. How many of your friends share your views on climate change? *

  None

  A few

  Some

  Most

  All
- Q12. Which of the following statements about climate change comes closest to your view? *

  Climate change isn't happening.

  Humans can't reduce climate change, even if it is happening.

  Humans could reduce climate change, but people aren't willing to change their behavior, so we're not going to.

  Humans could reduce climate change, but it's unclear at this point whether we will do what's needed.

  Humans can reduce climate change, and we are going to do so successfully.
- Q13. In the space below, list as many reasons as you can for why some people aren't taking climate change seriously.
- Q14. Do you think people themselves should be doing more or less to address climate change? *

  Much less

  Less

  Currently doing the right amount

More

Much more

- Q15. Over the past 12 months, how many times have you punished companies that are opposing steps to reduce climate change by NOT buying their products? *

  Never

  Once

  A few times (2–3)

  Several times (4–5)

  Many times (6+)

  I don't know
- Q16. Do you think that climate change should be a low, medium, high or very high priority for the President and Congress? *

  Low

  Medium

  High

  Very high
- Q17. People disagree whether the United States should reduce greenhouse gas emissions on its own, or make reductions only if other countries do too. Which of the following statements comes closest to your own point of view? The United States should reduce its greenhouse gas emissions . . .

  Regardless of what other countries do.

  Only if other industrialized countries (such as England, Germany and Japan) reduce their emissions.

  Only if other industrialized and developing countries (such as China, India and Brazil) reduce their emissions.

  The U.S. should not reduce its emissions.

  I don't know.

Appendix C. Percentages of Student Responses to 14 Quantitative Survey Questions Prior to, after the Completion of, and Two Years after Participation in the LC

Question numbers listed in the upper right hand corner of each panel correspond with the question numbers in Table 1. Since Q3 was mistakenly omitted from the senior survey, the student responses to that question are not included.

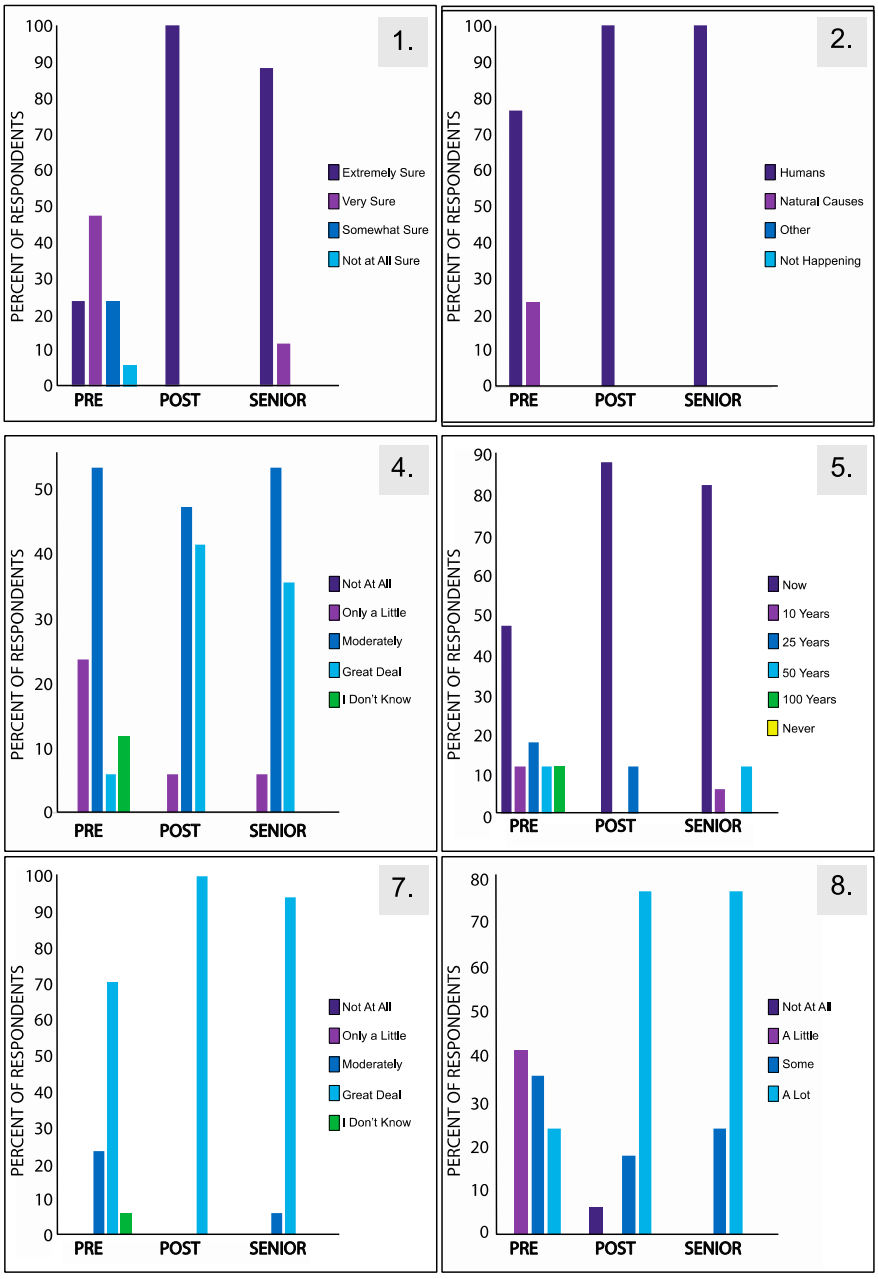

Figure A1. *Cont.*

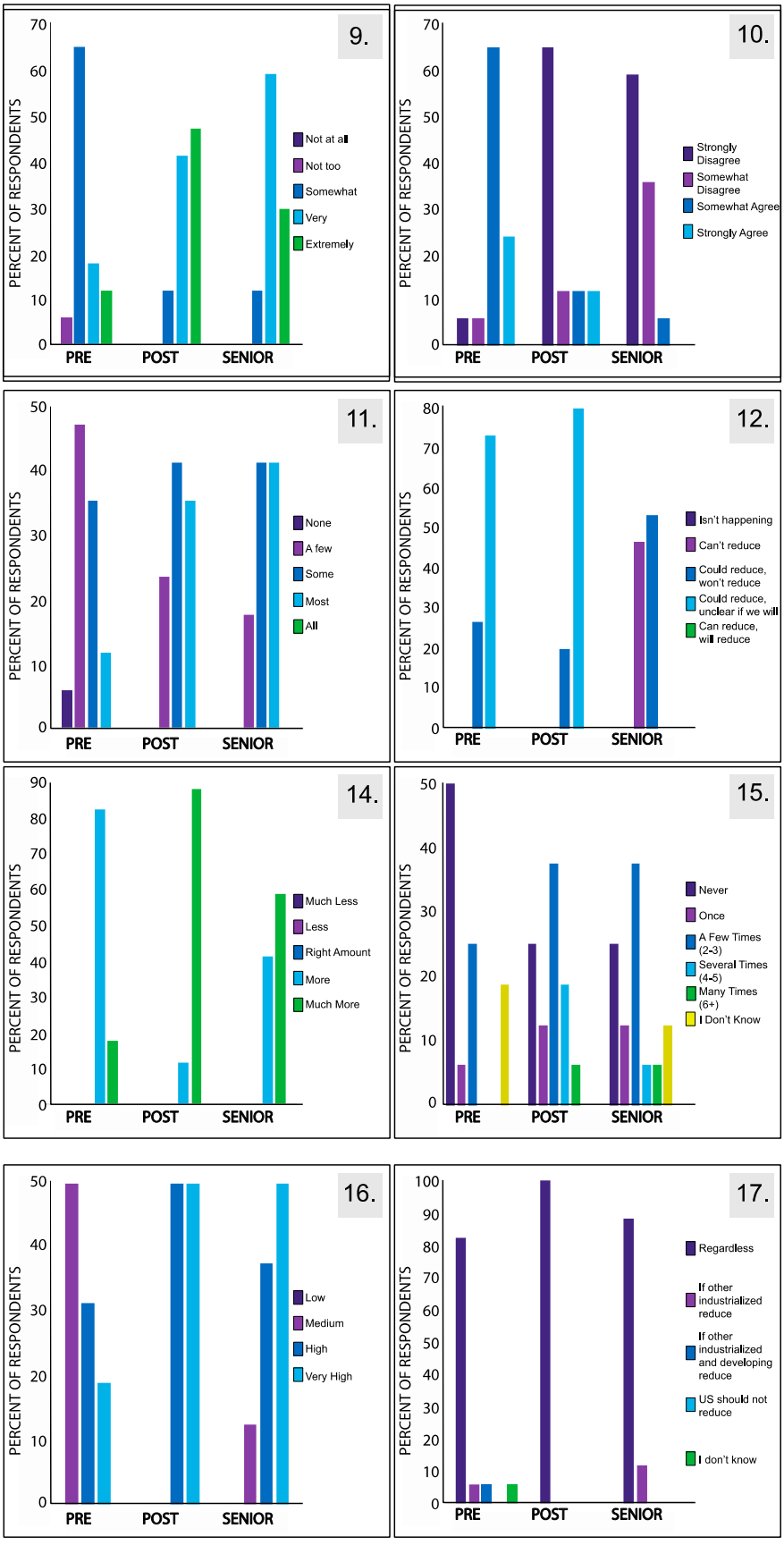

Figure A1. Percentages of student responses to 14 quantitative questions prior to, after the completion of, and two years after participation in the LC.

Appendix D. Descriptive Statistics of Overall Class Responses

Except for open response questions 6 and 13, lower mean indicates directionality of change toward greater climate knowledge, certainty, concern, and urgency. Please note, these overall patterns were not the subject of statistical analysis; change in each student's responses over time was the relevant parameter, and that statistical analysis is reported in Table 1.

Table A2. Descriptive statistics of overall class responses.

Question #(with Brief Note on Focus of Each Question)	Descriptive Statistics (Class Overall)						
		Pre-LC		Post-LC		Senior	
	n	X	SD	X	SD	X	SD
Q1. Happening?	17	2.1176	0.8575	1.0000	0.0000	1.1180	0.3420
Q2. Natural or human-caused?	17	1.2354	0.4372	1.0000	0.0000	1.0000	0.0000
Q3. Worried?	17	2.0000	0.6124	1.0000	0.0000	N.A.	
Q4. Personal harm?	14	3.2143	0.5789	2.6429	0.6333	2.7143	0.6112
Q5. When harm?	17	2.2941	1.4902	1.2353	0.6642	1.4118	1.0037
Q6. List impacts.	17	3.8235	1.5904	7.0000	2.1506	5.8235	2.1282
Q7. Harm future people?	16	2.2500	0.44721	2.0000	0.0000	2.0625	0.2500
Q8. Thought about before?	17	2.1765	0.8090	1.3529	0.7859	1.2353	0.4372
Q9. How important to you?	17	2.6471	0.7859	1.6471	0.7019	1.8235	0.6359
Q10. Could change my mind?	17	3.0588	0.7476	1.7059	1.1048	1.4706	0.6243
Q11. Friends share views?	17	3.4706	0.7998	2.8823	0.7812	2.7647	0.7524
Q12. Closest to your view?	15	2.2667	0.4577	2.2000	0.4140	3.4667	0.5164
Q13. Reasons why some don't . . .	17	3.2353	1.0325	5.0000	1.4142	3.9412	2.1929
Q14. Should people do more?	17	1.8235	0.3929	1.1176	0.3321	1.4118	0.5073
Q15. Boycott opposing corps?	11	4.3636	0.9244	3.1818	1.2504	3.5454	1.2136
Q16. Priority for federal gov?	16	2.3125	0.7932	1.5000	0.5164	1.6250	0.7188
Q17. Should US act . . . ?	16	1.1875	0.5439	1.0000	0.0000	1.1250	0.3416

Appendix E. Supplemental Questions Asked Only of Seniors in 2016

1. How much do you think the Climate Change LC contributed to your continued interest in the issue during your junior and senior years? Use the slider to choose along this range of 10 (0 for not at all; 5 for somewhat; 10 for very significantly)

n	Mean	SD	Range
16	8.44	1.59	5–10

2. In the last week, at how many meals did you choose to eat foods at least partly because of their lower carbon footprint (e.g., more veggies, less meat)? Choose 11 if more than 10.

n	Mean	SD	Range
15	5.47	3.91	0–11

3. In the last week, how many times did you lower your energy use at least partly to decrease carbon emissions (turn out lights, unplug chargers, lower heat, etc.)? Choose 11 if more than 10.

n	Mean	SD	Range
17	7.88	3.12	2–11

4. In the last month, how many times did you choose transport at least partly because of its lower carbon footprint (e.g., mass transit, walk, cycle)? Choose 11 if more than 10.

n	Mean	SD	Range
15	3.67	1.91	0–7

5. In the last six months, how many times have you chosen to read/view a news report on climate change? Choose 11 if more than 10.

n	Mean	SD	Range
16	8.44	2.66	3–11

6. In the last six months, how many times did you contact a political (or college) leader to ask for climate change policy or action? Choose 11 if more than 10.

n	Mean	SD	Range
11	1.36	1.80	0–5

7. In the last six months, how many times did you take action (e.g., sign a petition, choose to attend an event, march or rally) focused on addressing climate change? Choose 11 if more than 10.

n	Mean	SD	Range
13	2.46	2.50	0–8

8. Beyond climate change literacy, in what other ways do you think the LC experience influenced you? Please answer in the space below.

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