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Interdisciplinary Growth of Sustainability-Minded Engineers through Conservation Technology

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ABSTRACT

To address global challenges such as climate change, we must prepare an engineering workforce of sustainability-minded engineers ready to tackle complex socio-technical problems with multiple stakeholders. Frameworks like the United Nations (UN) Sustainable Development Goals (SDGs) have begun to drive structural changes in engineering education, including new ABET accreditation focused on sustainability. The emerging field of conservation technology allows engineers to develop sustainability competencies and identities as conservationists and environmentalists while advancing their technical and problem-solving skills. This manuscript describes student identity development in conservation and environmentalism in the Tech4Wildlife (T4W) Vertically Integrated Project (VIP) course at Georgia Tech. The course uses human-centered design principles and the UN Sustainable Development Goals in a project-based learning pedagogy to enable students to solve conservation-oriented, real-world problems and develop a sustainability mindset. A mixed-methods approach incorporated in-person interviews and a post-course survey assessment to assess course impacts and student identity formation. The sample consists of undergraduate students from the College of Engineering and the College of Computing. Based on a sample of 20 of the most recent students, students experienced an identity shift, moving from a mindset of "engineer" and/or "programmer" with no sustainability knowledge to showing significant growth in conservationist and

environmentalist mindsets by the end of the course. To educate and develop the next generation of sustainability-minded engineers, interdisciplinary, project-based courses grounded in Sustainable Development Goals may offer a meaningful pedagogical approach for students to develop advanced technical skills and conservationist identities.

Key words: Tech4Wildlife, AI4Good, Human-Centered Design, Sustainable Development Goals, SDGs

INTRODUCTION

In 2015, the United Nations released the Sustainable Development Goals (SDGs) to provide a framework for addressing global challenges across non-profits, industry, politics, and education (Gostin & Friedman, 2015). The vision for a sustainable future on Earth is summarized in 17 individual goals, similar to those of the National Science Foundation's (NSF) Big 10 Ideas and the Grand Challenges proposed by the National Academy of Engineering. A primary driver of the SDGs is the need to develop new and innovative solutions to sustainability challenges caused by climate change, including food insecurity, public health crises, and inequality (El-Jardali, Ataya, & Fadlallah, 2018). Many colleges and universities use the SDGs to guide research, scholarship, and service (Leal Filho et al., 2019). The SDGs have also gained pedagogical traction with educators as High Impact Practices, or HIPs–guides for classroom learning settings (Ferraro, Etzion, & Gehman, 2015; Gostin & Friedman, 2015; Gropp, 2016; Tang, 2017), which include the known practices of capstone projects and community-based learning (AACU, 2022). Currently, curricular integration of the SDGs in higher education programs varies widely, from "add-on" approaches that create a new major or certificate, to integration across the core curricula and even profound curricular transformations described as "Education as Sustainability" (Weiss, Barth, Wiek, & Wehrden, 2021). In 2001, the Vertically Integrated Projects (VIP) model was developed at Purdue University, enabling faculty to advance research projects by mentoring large teams across different under- graduate and graduate career levels (Sonnenberg-Klein, 2023; Sonnenberg-Klein & Coyle, 2022). The model has since been implemented at more than 40 institutions worldwide. VIP adheres to the following standards: 1) projects are embedded in the faculty mentor's research, scholarship, or exploration, 2) projects are long-term and large-scale, lasting many years, 3) the program is curricular, 4) students can participate for multiple semesters; 5) learning outcomes include both disciplinary and professional skills (Marshall et al., 2014). While not required, VIP problems are often interdisciplinary or multidisciplinary, bridging disciplines such as Mechanical Engineering with Computer Science (Ferri et al., 2017). Through VIP, faculty can develop new ideas (such as conservation technology) in a low-stakes setting while

engaging undergraduates in novel learning experiences without significant changes to the curricula or typical engineering degree requirements (Burgess, Childress, & Weaver, 2015).

Conservation Technology (CT) is an overarching term for wildlife and environmental conservation developments. Currently, most CT efforts leverage hardware and software design processes to initiate or improve conservation efforts (Berger-Tal & Lahoz-Monfort, 2018). Some of the major goals of CT are to improve outdated equipment, increase accessibility to tools, and use modern technology to address conservation problems in entirely new ways. For wildlife in particular, CT is being developed for both animals' natural environments (in-situ) and captivity settings (ex-situ)– (e.g., foxes and elephants, respectively) (Pacheco, 2018). Initially, the conservation biology community was dismissive of new technologies, but biologists have recently begun to embrace and even assist in developing new conservation tools and solutions (A. Schulz & Shriver, 2022). Unlike many discipline-specific engineering endeavors, every CT development requires meaningfully interfacing with the conservation community, technologists, and policymakers to ensure a successful outcome (Berger-Tal & Lahoz-Monfort, 2018; A. K. Schulz, Gouge, & Madliger, 2024; Sintov, Seyranian, & Lyet, 2019). Many CT design challenges include engineering requirements or constraints, public policy issues, wildlife management, data analytics, and ethical considerations. New technology is not considered conservation technology until its usefulness and success are demonstrated in the appropriate setting.

The field of CT utilizes collaborations with conservation practitioners such as zoological organizations. Nearly 600 million people visit over 1300 zoos and aquariums worldwide each year (Kahlon, 2021). While education is a primary goal of zoos, it is not a primary reason that people go to zoos (Packer & Ballantyne, 2010). At zoos, aquariums, or even museums, visitors can make personal connections and control their learning environments, which has long-term impacts (nearly 10% of visitors change their daily actions at home, such as reduction of the use of single-use plastics or discussing environmental issues with peers) (Packer & Ballantyne, 2010). Zoos are ideal ex-situ environments for conservation technology developments and serve as critical information sources about animal behaviors in both in-situ and ex-situ conservation technology challenges (A. K. Schulz et al., 2022).

CONSERVATION TECHNOLOGY COURSE STRUCTURE

The Tech4Wildlife VIP course is built around the four-phase framework of human-wildlife-centered design. The semester begins with **education** on broad concepts, including human-centered design, conservation science, frugal technology, and technological interventions. We then pair interdisciplinary student groups with conservation leaders in the field to provide specific expertise and allow them to **design** a conservation tool to help the organization and the impacted species. Students work

through the engineering design process to **test** the validity of their design and, after iteration, **deliver** the final conservation tech tool (A. Schulz, Greiner, et al., 2022). Delivered solutions are monitored and potentially iterated in future semesters of the VIP course. When the Conservation Technology course was first established at Georgia Tech in the Fall of 2019, the class size was four students working on two projects. In the Spring of 2022, 20 students worked on six different projects and partnered with various wildlife conservation organization partners.

Course Learning Objectives

The T4W course draws undergraduate students from computer science, engineering, and biology. The course content is designed to augment students' understanding of their disciplines and the potential for impact on the world while developing cross-cutting content knowledge and processes that empower students to tackle cutting-edge problems specific to Conservation Technology. As such, the learning objectives for the Conservation Technology course are as follows.

Students will:

- Identify examples of conservation technology & human-centered design
- Review and critique current CT projects using human-centered design principles
- Design and submit an interdisciplinary CT project to an online digital maker space
- Explain the historical issues in conservation technology and advocate for utilizing human-centered design to help wildlife and the environment
- Analyze current CT practices, including tracking, monitoring, software, and hardware technologies used in the industry
- Communicate with international leaders in species conservation

To achieve these learning objectives, the course follows the sequence described below.

Education Phase - A Sustainability Foundation

The first five weeks of the course, known as the Education Phase, are focused on active learning scenarios and case studies that prepare students for their team project. This helps students transition to the fundamental concept of the course, *human-wildlife-centered design*, which combines human-centered design with human-wildlife conflict. In conservation biology, human-wildlife conflict is a prevalent challenge, with examples ranging from humans invading animals' native habitats to disease transmission of urban wildlife such as coyotes, foxes, and monkeys in dense urban areas. During this phase, students learn methods for creating a successful conservation technology artifact. Students build a foundation for collaboration between unrelated disciplines and a framework for working with external partners, skills which are often unaddressed and underrated in typical engineering coursework.

The core concepts for the education phase are the design process, sustainability, and wildlife conservation principles. We begin with a primer on human-centered design. Our approach to human-centered design is grounded in the IDEO framework discussed in the project-based engineering education setting by Mueller et al. (Mueller et al., 2020). In addition, we introduce the United Nations' sustainable development goals as a framework for evaluating potential designs.

Sustainability Student Outcomes

In our class, we approach sustainability fundamentals from the biological perspective of conservation of the environment through assisted technology. Sustainability in engineering is often focused on energy, circular design, materials usage, etc. In this course, human-wildlife-centered design is the lens through which sustainability is viewed. Specific lessons include ecosystem sustainability and preventing ecosystem imbalance. Case studies are cited, such as geolocators on birds that allow increased data acquisition but alter their migration, breeding, and egg-laying behaviors, decreasing their successful nest-producing behavior from 78% to 25% (Arlt, Low, & Pärt, 2013). Do no harm is a core tenet of conservation technology, much as in other research disciplines involving some level of risk to participants (A. K. Schulz et al., 2023).

The course also examines sustainable energy through the lenses of biology and engineering. We discuss both material usage (e.g. use of biodegradable materials) and sustainable data usage (e.g. computer vision models for wildlife conservation), which can be incredibly effective (Tuia et al., 2022) but also incur emissions costs leading to climate impact (Luccioni & Hernandez-Garcia, 2023).

Finally, we adopt culturally responsive pedagogy rooted in indigenous and community-engaged design. Indigenous design promotes social responsibility and an environmentally engaged division based on the sustainability of natural systems (Sheehan, 2011), with community-engaged design emphasizing inclusion of community stakeholders throughout the design process. Using case studies, students are taught to evaluate the ethics and effectiveness of conservation technology and how to best incorporate and honor indigenous practices. We specifically expose students to a framework of community involvement from contractual to indigenous community participation, highlighted by climate scientists David-Chavez and Gavin (David-Chavez & Gavin, 2018). Through higher levels of community involvement and indigenous design in conservation, tech projects may become more sustainable with respect to both adoption and environmental impacts.

Design Phase - The Conservation Tools of Tomorrow

The design phase of the course transitions students from individual learners versed in the unique needs of conservation technology to team members ready to design and build solutions. First, students individually apply conservation technology principles through a documentary review. During

the documentary review, students watch a curated list of documentaries and ideate potential technological solutions to identified problems. Additionally, students include a discussion of possible improvements to existing technologies depicted in the documentary. This completes the individual portion of the course; the remainder of the course is structured around team assignments.

Once the course fundamentals and **conservation education** have been covered, we form interdisciplinary teams of engineers, biologists, and computer scientists. These teams are paired with conservation leaders for local, domestic, and international projects to establish **multinational collaborations**. For each project team, students work to bring forward human-centered design and work to counter the historical colonization of conservation that has been done in the CT space. Finally, students work to conduct or inform ethical experiments by working with the Institutional Animal Care and Use Committee (IACUC) for animal-related work as well as the Institutional Review Board (IRB) for human-related work and associated research students. Both entities ensure minimal risk and harm to research populations relative to the scientific benefits.

During the team-based portion of the course, teams meet weekly outside of class time and document their progress in design notebooks. These designs are reviewed (and graded) throughout the semester. Students also use the notebooks to document their personal goals, design goals, successes, and setbacks. As part of the design phase, students consider possible fabrication techniques, create a bill of materials, and compare their designs to other case studies using evaluation matrices. Students define customer needs and perform market analysis on conservation groups that could or potentially utilize their designs. Presentations and peer review, in addition to the design notebooks, are used to provide feedback to students throughout the semester. As the VIP spans several semesters, course alumni serve as mentors for new students. Peer support is a unique and vital aspect of a successful VIP program and enhances students' networks and sense of community(Sonnenberg-Klein, Abler, & Coyle, 2018).

Test Phase - Engineering Iteration of Conservation Tech

Following the design phase, this phase begins when the students have completed a test prototype and meet with their project partners from the conservation community. Testing devices in the in-situ or ex-situ environments requires careful coordination with the partners to ensure proper implementation and minimal risk to animal and human participants. Examples of test implementation could include distributing camera traps around campus, going to the zoo to hang up a feeder, or sending hardware to a non-local project partner.

The testing phase reveals the prototypes' strengths and limitations based on the behaviors of the animals and feedback from the project partners. In this phase, students identify design flaws, technical glitches, and unforeseen challenges, including 3D-printed parts not interfacing, material constraints due to environmental conditions, and software bugs that had not been detected previously. These

findings enable students to refine their prototypes and enhance their ability to adapt to dynamic, real-world situations and think critically when faced with unexpected obstacles. The testing phase goes beyond technical challenges; it also fosters collaboration, promoting interdisciplinary discussions and knowledge exchange among students, instructors, and project partners.

Testing is iterative and generally occurs several times as students iterate through different prototype models. During the testing phase, the sustainability of the design is evaluated by both the project partners and instructors. Evaluation of the sustainability of the design is primarily assessed through raw material usage as well as environmental waste and/or potential harm from the design. We communicate with the project partners the need for their designs to be sustainable and we are able to evaluate the sustainability of the products based on purchases necessary. Also, for students engaged in more computational projects, we evaluate the sustainability of their design through their midterm presentations evaluation and assessment as part of the rubric is on sustainability and making sure their design does-no-harm wherever they are proposing it be deployed.

Deliver Phase - Tools in the Field

At the end of the semester, students connect with experts in the field who are working on conservation technology challenges around the globe. These experts are different from their project partners, who are researchers and scientists in the conservation technology field who are invited as guests. Examples include people from WILDLABS (https://wildlabs.net/) conservation technology community and researchers from AI4Good. These experts also include faculty from our institution specializing in sustainability, animal behavior, and computer vision for wildlife. Experts are recruited via email as well as marketing on social media requesting experts and early career scientists to assist with the conservation technology course.

These conservation technology experts in hardware, software, scientific discovery, and frugal development all provide valuable insight to students. By receiving this type of external feedback at the end of the semester, students can obtain fresh perspectives as they finalize prototypes for delivery to project partners. As the course has evolved and projects have become more complex, students may produce multiple prototypes over multiple semesters, with the following design phase acting as a redesign/iteration phase instead. In this case, feedback from the conservation technology experts is also directly incorporated into final write-ups so the next cohort of students working on the project already know of any new directions worth pursuing.

Project Example

To provide a concrete example of an interdisciplinary project between engineers and scientists, we present a project that began in the Spring of 2020 and concluded in the Spring of 2022. The

external partner is Zoo Atlanta, who wanted to create more realistic foraging behavior for gorilla populations in captivity (ex-situ). The T4W student team designed a randomized automated feeder to emulate wild gorillas' diets and feeding schedules. Students were initially provided with a rough idea of the project based on the zoo's identified needs. The zookeepers had unsuccessfully attempted to connect a car battery and a store-bought deer feeder but could not re-purpose the device within the Zoo Atlanta gorilla habitat. They were excited to advise a team of undergraduates in developing a better solution. The team began by meeting with the head gorilla keeper at Zoo Atlanta to understand what the device would need to do and how to test the validity of a finalized prototype. The device's final design was completed at the beginning of Spring 2022. Students received consistent and frequent feedback over the four semesters and underwent several iterations before achieving the final design. The final project is easily replicated using handheld tools, a 3D printer, and a mass-produced printed circuit board (PCB) design, allowing zookeepers and other conser- vation community members with less engineering experience to implement this design in different sites with minimal instruction. The hardware for this case study was eventually published in the journal HardwareX by Jadali, Zhang, and Schulz et al. (Jadali, Zhang, Schulz, Meyerchick, & Hu, 2023).

Assessments and Grading

The course has a range of assessments for both feedback and grading. These assessments include:

- Notebook - Includes student documentation of weekly accomplishments and goals. It adheres to VIP standards for documentation and learning.
- Annotated Bibliography - This is a beginning-of-the-semester assignment that helps students understand existing technological solutions in the wildlife world.
- Peer Evaluations - An important component of the VIP team experience is peer evaluation. Students evaluate classmates with whom they work, with one evaluation midway through the term and one at the end of each semester.
- Species Case Study - This assignment guides students through understanding their target species. Each student writes a two-page reflection on a current species on the red list of the International Union for Conservation of Nature (IUCN). This assignment is given during the education phase, and students are given agency to select their preferred deliverable, such as an infographic, essay, or recorded presentation.
- Presentations - Each team is expected to give a 10-minute presentation on their progress for their project several times during the semester. There is also a final culminating presentation.
- Final Project Report - The final report is both a grading opportunity and a transition document for the team continuing the project next semester. This report should go beyond the

final presentation with details that enable the next team to replicate and reproduce designs and results.

METHODS

To understand the impacts of the Conservation Technology course at Georgia Tech on student participants, we sought to answer the following research questions:

- What is the impact of the T4W course on identity formation with respect to environmentalism and conservation?
- How do these impacts differ for students from different colleges?
- What aspects of the T4W course motivate students to participate?

To begin to answer these questions, qualitative methodologies were employed to explore avenues for future quantitative studies. In-person structured interviews were used to elicit responses from participants, with Georgia Tech's Institutional Review Board (IRB) approval. Past and current students in the GaTech4Wildlife course were recruited to participate, and nine individuals were interviewed. Each interview lasted no longer than 30 minutes, in which we employed the following structured interview protocol:

1. If you have taken multiple VIP classes, how did the GaTech4Wildlife VIP course compare to other VIP classes you have taken?
2. What aspects of the GaTech4Wildlife VIP course did you find to be effective?
3. Are there any specific elements of the GaTech4Wildlife VIP course that built interest and engagement?
4. How did the traditional assignments (case study, documentary review) affect your experience in the GaTech4Wildlife VIP course?
5. How did the experts/guest speakers affect your experience in the GaTech4Wildlife VIP course?
6. How did the project-based learning format affect your experience in the GaTech4Wildlife VIP course?

During the interviews, participants could discuss their answers without any time limitations, but the protocol was designed to take 30 minutes. Each interview was concluded by asking participants if they had any other feedback or thoughts they would like to share regarding their experience in this course. In total, nine students participated in the structured interviews.

Thematic analysis was applied to the interview data following transcription, which was completed using Rev.com - names and personal information were not included in the interviews or transcriptions. Once transcribed, we used a grounded theory approach to develop a code book and guide a thematic analysis. Emergent themes are defined and then exemplified using illustrative quotations

from students. A summary of the common themes and illustrative quotations are detailed in (A. Schulz, Patka, et al., 2022). Based on our analysis, we found that the following four themes from our interviews all appear in over 75% of representative interviews:

- Hands-on team project experiences in conservation tech
- Exposure to research opportunities for individuals to apply learned knowledge to conservation
- Eye-opening perspective on using technology to conserve wildlife
- Connections made among varying disciplines during the course

These results informed a quantitative survey, which probed further into these themes and themes from previously published literature.

Quantitative Survey Data

The focus of the quantitative study is primarily on identity development around conservation and sustainability. The survey also probed more deeply into motivations for participating in the course. The 15-question, 5-minute online survey was administered using the Qualtrics (Seattle, USA) soft- ware platform. The survey was divided into three main sections: (1) acknowledgment of consent to participate in the research study, (2) background information, including gender identity (if comfortable), amount of time in VIP, and college at Georgia Tech (3) gauging pre-class and post-class identities as well as motivation for enrolling and participating in the course. The survey concluded with a question about end-of-course takeaways. The survey is displayed in the supplement.

We distributed the survey to students participating in the VIP course during the 2022 spring and fall semesters. The survey was distributed after the final reports were turned in, as there were survey questions about them. No incentives were given to survey participants, and it was purely voluntary. We had five participants fill out the Spring 2022 survey and five respondents in Fall 2022.

We used Qualtrics reports to view responses, averages, and standard deviations, then RStudio and Adobe Illustrator to visualize data distributions in divergent bar graph formats. DataWrapper and MATLAB were used for additional data visualizations.

Statistical testing was performed on influential course components and shifts in student identities throughout the course. In all data cases, the Shapiro-Wilk test was used to determine normality, and Levene's test was used to assess the homogeneity of variances. If the data samples had normal distributions and similar variances, parametric t-tests were used. If the data did not have normal distribution or non-homogeneity of variances, non-parametric t-tests were used. In the case of the influential course component, the data samples are independent; therefore, a Mann-Whitney U-test was used. In the case of comparing student identities, a Wilcoxon Signed-Rank test was used for the sum of all student responses and dependent paired t-tests were used in the separation of the colleges.

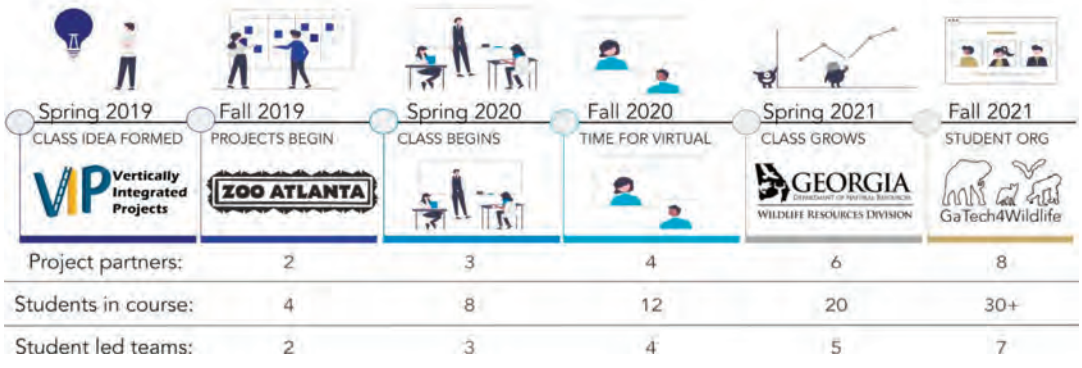
RESULTS

Summary of Tech4Wildlife Course Success

The T4W course began in the Spring of 2019 and has steadily grown in team size, number of project partners, and number of projects (**Figure 1**). From the data provided by the VIP program, since the course's inception in the Fall of 2019, the course has enrolled a total of 58 students, with 40 students identifying as female, 16 as male, and two not marked male or female. This study focuses on Spring 2022 and Fall 2022 where 18 and 9 students worked on conservation technology projects, respectively. Prior publications reported the overall course objectives (A. Schulz, Greiner, et al., 2022) as well as themes of the course that have made it successful (A. K. Schulz et al., 2022). The two most prominent themes that all interviewed students mentioned are foundational framework themes of the VIP Program: interdisciplinary teams and hands-on project experiences (Sonnenberg-Klein et al., 2018).

Pre-Course Student Identity

At the start of the T4W VIP course, students fill out an interest form describing their motivation to join the team (**Figure 2**). Survey respondents included six College of Computing students, three College of Engineering students, and one College of Science student. The most important themes for students on a scale from one (not important) to seven (extremely important) applying to the course were (n=9, as one participant left this question blank): working with/about animals (5.66 ± 0.67), conservation of wildlife (5.22 ± 1.0), communication with experts (4.89 ± 1.10), interdisciplinary work (4.67 ± 0.94). We see that working with animals significantly impacts course interest, beyond the level that research, interdisciplinary work, or addressing sustainable development goals influences students to participate (**Figure 2**, Table 1).



Project partners:	2	3	4	6	8
Students in course:	4	8	12	20	30+
Student led teams:	2	3	4	5	7

Figure 1. Timeline of the course through the first six semesters. Including milestones achieved in each semester and highlighting the expansion of the course. The bottom table displays the number of partners, students, and project teams over the years.

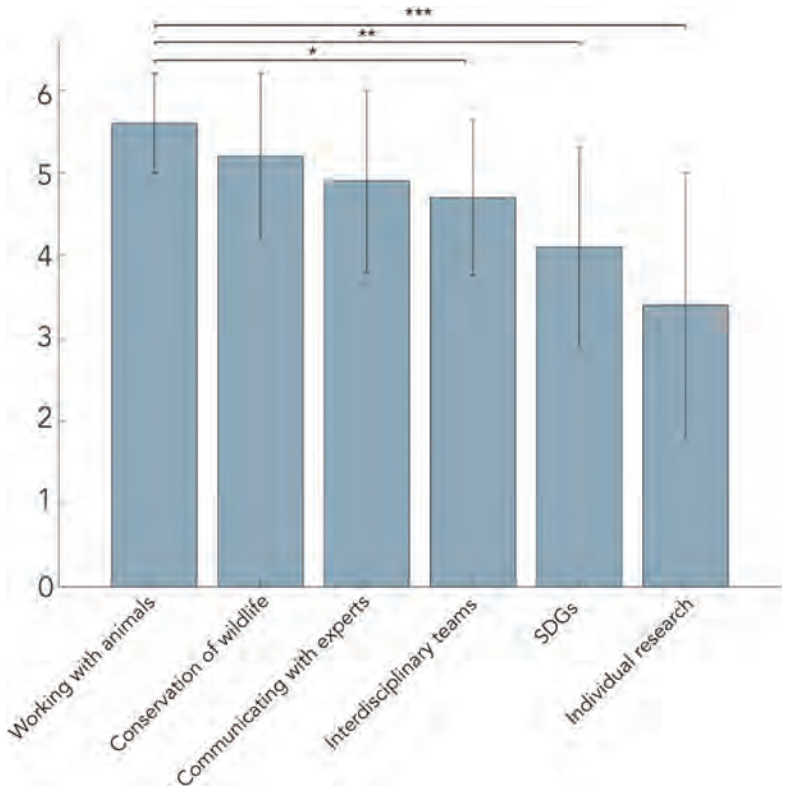


Figure 2. Ranking of the reasoning of students' reasons for applying to the course ranging from those statements students do not identify with (0) to identify with (6) strongly. Exact values are shown on p-value indicators of * ($p < 0.05$), ** ($p < 0.01$), and *** ($p < 0.001$).

Table 1. Student statistics outputs from response to: **How influential were the following course components regarding your decision to apply to this specific VIP course?** ***with p-values indicating the difference from the highest result of working with animals.***

Course Component:	n	Mean ± Std.	p-value
Working with/about Animals	9	5.67 ± 0.67	n/a
Conservation of Wildlife	9	5.22 ± 1.03	p = 0.22, d = 0.6
Interdisciplinary Work	9	4.67 ± 0.94	**p = 0.014, d = 1.29**
Sustainable Development Goals	9	4.11 ± 1.20	**p = 0.0028, d = 1.66**
Individual Research	9	3.44 ± 1.57	**p < 0.001, d = 2.01**
Communication with Experts	9	4.89 ± 1.10	p = 0.069, d = 0.92

computer science students in the course's history identifying as female or non-binary, both of which are underrepresented in the engineering and computer science fields. Working with animals may contribute to this participation rate.

The least influential portions of joining the class are the sustainable development goals (4.11 ± 1.12) and individual research (3.44 ± 1.57). Students may be unfamiliar with the SDGs before joining the course and/or not unique to the T4W VIP (**Figure 2**, Table 1).

Analyzing the students' prior course expectations, we found that most of our respondents were in their first semester in the GaTech4Wildlife VIP course, with 75% indicating it was their first semester. Before attending the course, we gauged students' identities across the categories: conservationist, engineer, biologist, technologist, programmer, and environmentalist (**Figure 3**A-D). Computing (n=6) and Engineering students' (n=3) initially self-identified more strongly in the technology-centered identities, including engineer (3.85 ± 1.55), technologist (4 ± 2.07), and programmer (3.86 ± 1.64). Students identified less strongly as biologists (1.71 ± 1.98), conservationists (3.1 ± 1.7), and environmentalists (3 ± 1.58) (**Figure 3**B-C).

The student in the College of Sciences had identities opposite those of engineers and computer scientists (**Figure 3**D). This may be a result of this individual student's attributes and/or the coursework that this individual had experienced prior to the T4W course. Nearly all engineers and computer scientists (*n* = 85%) indicated they had taken less than two courses on sustainability and environmentalism. By contrast, they indicated more than four courses on engineering design, computer science, and project-based learning. The only student with prior biology course experience was from the College of Sciences. Prior work has shown that Tech4Wildlife is often the first biology- related course engineering and computer science students have taken since introduction to biology in high school (A. Schulz, Patka, et al., 2022).

For post-graduate plans, pre-survey responses indicated interested in graduate school, project management, or non-profit work. They did not often cite conservation work or research as a likely next step (**Figure 4**A).

Student Perceptions of Course Elements

With the class being project-based, the only summative assessments are the end-of-the-semester report and presentation. During the semester, several formative assessments have little impact on the student's overall course grades but are used pedagogically for feedback and iteration (**Figure 4**B). When students were surveyed about specific course elements, the two most beneficial on a scale from zero to six were the summative assessments of the final report (5.14 ± 1.12) and the midterm/final presentations (4.5 ± 1.73). Students also enjoyed the career development aspect of the course near the end of the education phase module (4.3 ± 1.58). The students reported the

least beneficial experiences were the annotated bibliography (3.4 ± 1.73) and the notebook (3 ± 1.41). Every other assessment/portion of the course, guest speakers, peer evaluations, and specific case studies all exhibited means above 3.5, indicating that students felt they were helpful in the experience but were not key elements in their perceived learning journeys.

Course Themes and Key Outcomes

The primary course themes from the qualitative study, as described in detail in Schulz et al. for the GaTech4Wildlife VIP course, were as follows: (A. Schulz, Patka, et al., 2022)

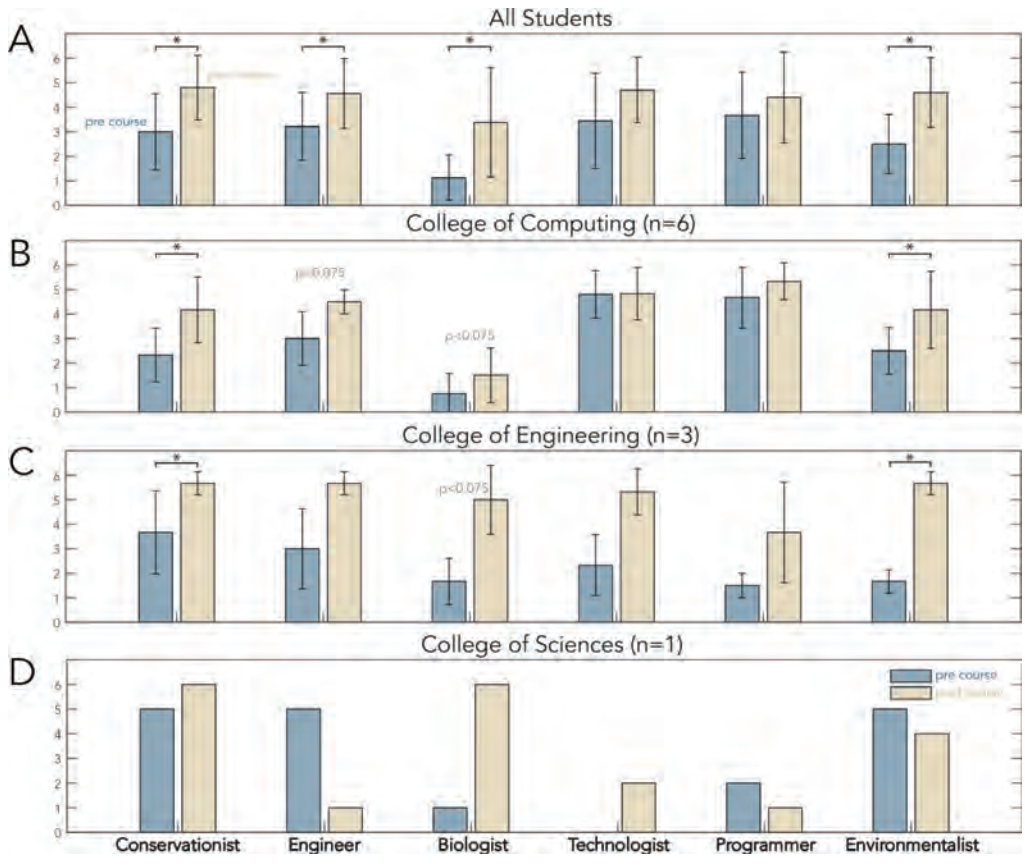


Figure 3. Pre and Post-course identity rasssnging from (0) not identifying to (6) strongly identity of students that have participated in the course with all shown cases of increase in students including: A) College of Computing student growth of (n=6) students, B) College of Engineering identity growth during the course (n=3) students, and C) College of Science individual growth (n=1) during the course. p-value indicators of * ($p < 0.05$). Several cases also showed ($p < 0.075$) with inset markers.

Table 2. Student identities pre and post-course, including all students, as well as identity score averages shown for the College of Computing (CoC), College of Engineering (CoE), and College of Sciences (CoS).

			Conservationist				Engineer		
College	Test Performed	n	Before	After	p-value	n	Before	After	p-value
CoC	Paired T-test (Dependent)	6	2.33	4.17	**p = 0.012**	6	3.00	4.60	p = 0.07
CoE	Paired T-test (Dependent)	3	3.67	5.67	p = 0.18	3	3.00	5.67	p = 0.15
CoS	n/a	1	5.00	6.00	n/a	1	5.00	1.00	n/a
All	Wilcoxon Signed-Rank Test	10	3.00	4.80	**p<0.05**	10	3.22	4.56	**p<0.05**
			Technologist				**Programmer**		
College	Test Performed	n	Before	After	p-value	n	Before	After	p-value
CoC	Paired T-test (Dependent)	6	4.80	4.83	p = 0.37	6	4.67	5.33	p =0.1
CoE	Paired T-test (Dependent)	3	2.33	5.33	p = 0.095	3	1.50	3.67	p = 0.09
CoS	n/a	1	0.00	2.00	n/a	1	2.00	1.00	n/a
All	Wilcoxon Signed-Rank Test	10	3.44	4.70	NUL	10	3.67	4.40	NUL
			Biologist				**Environmentalist**		
College	Test Performed	n	Before	After	p-value	n	Before	After	p-value
CoC	Paired T-test (Dependent)	6	0.75	1.50	p = 0.058	6	2.50	4.17	**p = 0.011**
CoE	Paired T-test (Dependent)	3	1.67	5.00	p = 0.063	3	1.67	5.67	**p = 0.02**
CoS	n/a	1	1.00	6.00	n/a	1	5.00	4.00	n/a
All	Wilcoxon Signed-Rank Test	10	1.13	3.38	**p<0.05**	10	2.50	4.60	**p<0.05**

- Hands-on team project experiences in conservation tech,
- Exposure to research opportunities for individuals to apply learned knowledge to conservation,
- Eye-opening perspective on using technology to conserve wildlife,
- Connections made among varying disciplines during the course.

Based on the survey developed from these key themes and outcomes, students felt strongly that the course positively impacted their experience at Georgia Tech (5.38 ± 0.7), the project-based structure contributes to its effectiveness (5.38 ± 0.7), and the class contributes to conservation efforts (5.38 ± 0.7). For most students, the course was their first experience with conservation (4.38 ± 0.7). The only statement that students on average disagreed with is that the course has influenced their post-graduate plans (3 ± 2.27). However, this response exhibited significant variance, likely indicating that it may have had a high impact on a few students.

Post Course Completion Identity

We asked students about their post-course completion identities after their first semester of the VIP course. When viewing all student participants across both semesters in the survey (n=10), we

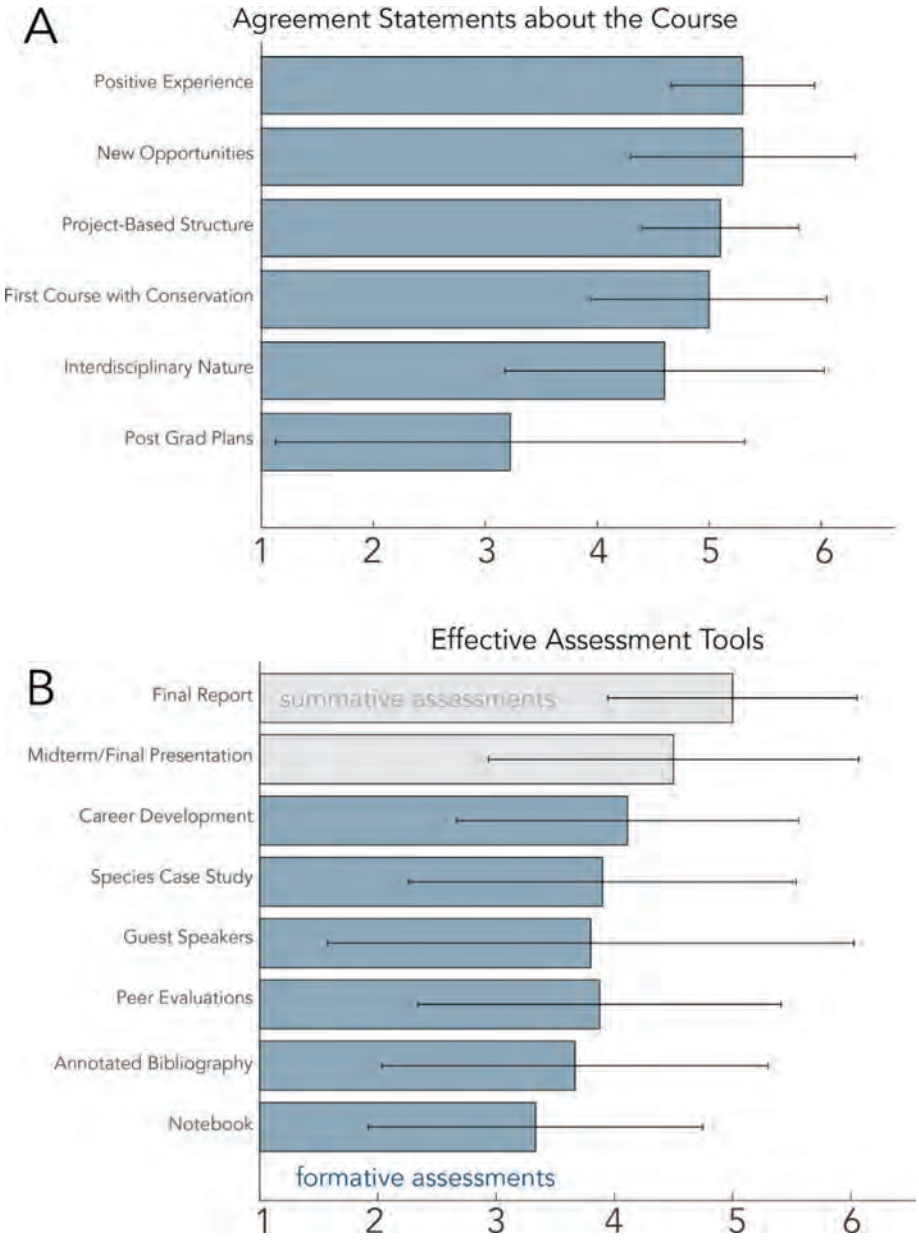


Figure 4. Post course completion evaluation of the course including A) students' level of agreement from (0) little to (6) greatly agree with statements regarding the overall course. B) Students' evaluation of which portions of the course are assessment tools, with blue bars indicating formative assessments and gold bars indicating summative assessments.

see a significant increase in conservationist, engineering, biologist, and environmentalist identities. While students also increased their technologist and programmer identities, the increases were not statistically significant (**Figure 3**A,Table 2).

We see further interdisciplinary identity shifts when we separate the identity growth based on the students' College. Students in the College of Computing significantly increased their identity as conservationists and environmentalists (**Figure 3**B,Table 2). We also see that for the students in the College of Computing, every student stated an increase in their Engineering identity (p=0.07) and Biologist identity (p=0.058), indicating a high confidence but not statistically significant.

In the College of Engineering, we see similar statistically significant identity increases for conervationists (5.2 ± 1) and environmentalists (4.7 ± 1). Engineers also indicated a nearly significant (p=0.063) increase in their biological identity after taking the course (**Figure 3**C,Table 2). The student in biological sciences increased their conservationist identity but did not see other increases as much as the computing and engineering students (**Figure 3**D). Significant identity changes ($p < 0.05$) occurred with both computing and engineering and computer science students identi- fying more strongly as conservationists and computing students also developing and engineering identity. Overall, after participation in the course, student identities converged with more students developing identities outside of their home disciplines with a bend toward conservation.

DISCUSSION

Addressing the Sustainability Gap

With the recent adoption of sustainable development goals, universities must adopt new pedagogical approaches that lead to more sustainability-minded graduates. Interdisciplinary courses, such as conservation technology, may support these efforts. Partners are key to the authenticity of these efforts–not just industry partners, but also non-profits and sustainability organizations such as Engineering for One Planet (Network, 2022), zoological organizations (A. K. Schulz et al., 2022), and sustainability startups. Partnering with these organizations and change-makers will allow universities to continue their rigorous engineering outcomes but focus the engineering design process on challenges proposed by sustainability-focused organizations (Nesbitt, Suzuki, Daneshvarn, & Ghouali, 2022).

Course Challenges

Students often have misconceptions about conservation through pop-culture themes such as scooping plastic out of the ocean, hunting, fishing, trophy hunting, zoo benefits for conservation, de-extinction, and more. To address these misconceptions, we begin each class by addressing one

major misconception in the conservation sector by watching a video and having a think-pair-share discussion. Additional challenges in implementing a CT course include politicization of conservation and sustainability, particularly in the United States. With ideas such as climate change and sustainable energy becoming more becoming politicized, we ground our discussions in the class with Sustainable Development Goals.

Starting Your Own Conservation Tech Course

To begin a course on conservation tech, we highly recommend instructors incorporate their own research interests and sustainability practices, which could begin in existing courses. The Georgia Tech course was constructed based on the author's previous experiences with biologically-inspired design education and conservation science.

Another key driver is finding community conservation partners. These partner organizations, like Zoos, foster real-world research and implementation opportunities, as well as a source of guest speakers and thought partners for future project development (A. K. Schulz et al., 2022). Many players in the conservation tech space have limited resources; connecting students with them to move projects forward can be a winning opportunity for all parties.

CONCLUSION

In this paper, we describe a novel conservation technology course taught in a project-based setting using the VIP integrative research paradigm and described its impacts on student participants. The structure of the course, learning goals, and example projects are provided for replication and future adaptation. Research results from qualitative and quantitative studies reinforce the key themes of the course and show that engineers and computer scientists developed conservationist identities after participating in the course. All students enhanced and strengthened their technical identities across disciplines.

LIMITATIONS & FUTURE WORK

While one semester is a reasonable intervention length, this study is limited to students' perceptions immediately after completing the course. Future studies should examine long-term outcomes of identity development for post-graduate years and impacts on career trajectory. In addition, this study is limited by the small sample sizes, particularly for the quantitative study. Future replication and administration of the survey to additional student cohorts would strengthen the results and statistical analyses.

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