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Nature as Mentor: Catalyzing First-Year Liberal Arts and Sciences Undergraduate Transition Through a Biomimicry First-Year Seminar

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University students crave immersive, collaborative, interdisciplinary, applied learning contextualized to real world sustainability challenges. Liberal arts and sciences institutions are particularly well positioned to respond. Here we report on our high impact, cross-disciplinary, biomimicry-themed first-year experience (FYE) curricula. Biomimicry is an emerging, multidisciplinary approach to innovative problem-solving that seeks to emulate functional biological adaptations to inspire more innovative, efficient, resilient, and regenerative solutions to human challenges. In the classroom, biomimicry fosters higher-order thinking, creativity, and imaginative problem-solving while teaching the fundamentals of functional biology, STEM research, communication, and systems thinking. The highly integrative, skills-focused, experience-based, and philosophy-grounded nature of our curricula is optimized for the liberal arts and sciences FYE mission. Our goal is for students to successfully begin their transition to the liberal arts and sciences undergraduate setting, relate more strongly to the natural world, and draw inspiration for human problem-solving from nature. Merging the first-year seminar and biomimicry pedagogies seems to amplify learning in both areas. We share highlights of our curricula and pedagogy to encourage the development of more nature-based biomimicry first-year seminars promoting global citizenship at other liberal arts and sciences institutions.

It is more vital than ever that we teach our students how to thoughtfully engage and actively change the world for the better. From the existential threat of climate change to issues of social and environmental racism to the COVID-19 pandemic, we face challenges that threaten our survival and undermine the planet's capacity to sustain life. These threats are prompting questions about how we got here and what to do about it. In response, we are challenging our basic assumptions, reevaluating what is important, and reimagining what is possible (Rousseau & Deschacht, 2020). The world our students are inheriting is riddled with wicked challenges that are a consequence of a range of social, political, and environmental crises (Hanstedt, 2018). Not only are these challenges complex, but they must also be addressed within dauntingly short timeframes (IPCC, 2018). With so much on the line in the present moment, current first-year undergraduate students may wonder whether four years devoted to academic study might be better spent engaged in activism and action rather than formal education.

Students crave immersive, collaborative, interdisciplinary, applied learning contextualized to real world scenarios, empowering them to make a difference through their studies and to practice skills relevant to the work that lies ahead. It is the responsibility of higher education to make sure our students are equipped with the knowledge, skills, and mindsets that will allow them to be successful in creating a more prosperous, life-sustaining future (Evans, 2019; Hanstedt, 2018). We need to enable global solutionaries, capable of tackling complex, systems-level social, environmental, and economic issues with determination, inventiveness, and actionable solutions (Evans, 2019; Hanstedt, 2018; Nagel & Pidaparti, 2016; Van der Wende, 2011). Liberal arts and sciences institutions are particularly well positioned to do so through the purposeful fusion of interdisciplinary, practical, concrete information with theoretical knowledge in applied scenarios that contextualize learning (Evans, 2019; Van der Wende, 2011).

First-year experience (FYE) programming in higher education aims to improve student engagement, persistence, and retention rates through academic support, high-impact student involvement, and an inclusive social community during a student's first year on campus (Astin, 1977; Tinto, 1993; Young & Hopp, 2014). The FYE movement was led by John Gardner at the University of South Carolina (USC) in the 1970s; USC's University 101 program formed the basis for modern first-year transition programming around the world (Gardner, 1980; Ryan & Glenn, 2004). Quality FYE programming has been shown to improve student success through fostering critical thinking and writing skills (Barefoot & Fidler, 1992; Kuh, 2008; Young & Hopp, 2014). Intellectually stimulating first-year programming that challenges students and holds space for learning is a vital first step towards creating whole, autonomous students prepared to engage as thoughtful change agents (Hanstedt, 2018; Padgett et al., 2013). Gallup polling has indicated that graduated students are two times as likely to feel well engaged and have a high sense of well-being at work if they had strong, caring faculty mentorship and support (Matson & Clark, 2020) and were able to engage with experiential learning experiences during their undergraduate education (Seymour & Lopez, 2015). A quality first-year experience can provide both (Cuseo, 2009).

First-year seminars have now become a standard feature at many liberal arts and sciences colleges and universities (National Resource Center, n.d.). A well designed first-year seminar at the threshold of a student's

higher education experience serves to ground them into their new environment, to orient them to the skills and resources they will need to succeed, to build a supportive community, and to instill an understanding of liberal arts and sciences philosophy. This transitional experience serves as the launch pad toward interdisciplinary higher-level thinking that frames and catalyzes their entire liberal arts and sciences higher education experience. Many first-year students are choosing their career paths for the first time and want to integrate broad, seemingly orthogonal interests (e.g., art and biology). Not yet set in any particular disciplinary track, their naivete can be an asset. A lack of preconceived constraints and limitations allows students to more creatively select and integrate their courses into an individualized toolbox of interdisciplinary skills and knowledge. First-year programming at Carleton College and the College of Charleston (CofC) both create student-centered academic rigor within a supportive learning environment that promotes engagement and a growth mindset while also serving as an introduction to a wide range of high impact liberal arts and sciences learning opportunities. Our seminars integrated peer mentorship from successful upper-level students. CofC's first-year experience courses utilize faculty-selected, paid, upper-level students as peer facilitators to lead weekly 50-minute synthesis seminars emphasizing successful academic and social transition. Carleton's first-year argument and inquiry seminars utilize upper-level students as writing assistants through the college's writing center.

Here we report on our independently developed, biomimicry-themed first-year seminar curricula, which provide opportunities for high-impact experiences in cross-discipline and value-based learning. Biomimicry (biomimetics, bionics, bio-inspired design) is an interdisciplinary problem-solving practice that draws on the biological world for inspiration. Biomimicry education fosters higher order thinking, creativity, and imaginative problem-solving while teaching the fundamentals of functional biology, STEM research, communication, and systems thinking (Nagel & Pidaparti, 2016; Nagel & Stone, 2011; Stevens et al., 2019; Wanieck et al., 2020). In addition to introducing students to this nature-inspired problem-solving practice, our curricula also emphasize the exploration of natural history and environmental philosophy. The highly integrative, skills-focused, experience-based, and philosophy-grounded nature of our curricula is optimized for the FYE mission, priming students to ground and thrive in their new campus homes as autonomous meaning makers, lifelong learners, and engaged citizens. These nature-based curricula are timely (Chow & Healey 2008; Snell-Rood et al., 2020). The number of students seeking to major in environmental studies continues to rise, especially at liberal arts and sciences institutions (Johnson et al., 2020; QS, 2019), and during our global COVID-19 quarantine pause in 2020, humanity was drawn to nature-rich activities in droves. Six in ten Americans have a new appreciation of nature due to the quarantine, and three in four say they are happier because they are spending more time outdoors (Network, 2020). Time spent outdoors, particularly closer to home, is increasing in two thirds of Americans polled, and a third of US citizens say they are spending more time outdoors than ever before (Network, 2020). Reports from Europe indicate similar changes in behavioral patterns. Surging attendance rates at national parks and urban forests, including a novel influx of families with children and visitors with no prior history of attendance, were strongly correlated with the lifting of lockdown restrictions during the COVID-19 pandemic (Derks et al., 2020; McGinlay et al., 2020). This surge in nature appreciation may make effective nature-based first-year experience curricula particularly attractive to incoming students.

While biomimicry and other nature-inspired disciplines are increasingly common within higher education, the bulk of degrees are offered at the graduate level, especially within the United States (Wanieck et al., 2020). When biomimicry is taught at the undergraduate level, engineering and design students are frequently the target audience (Eggermont, 2008; Nagel et al., 2016; Nagel & Pidaparti, 2016; Nagel et al., 2019). A handful of US undergraduate biomimicry courses, minors, or certificate programs have been either proposed (Urmann, 2015) or implemented (e.g., Arizona State University, n.d.; College of Charleston, n.d.c.; University of Akron, n.d.). There remains much opportunity to introduce interdisciplinary biomimicry early in an undergraduate program of study, allowing students to incorporate its tools and mindset into how they shape their undergraduate plan of study, senior projects, and, ultimately, their careers. Our undergraduate level biomimicry-themed FYE curricula respond to this opportunity. We share our teaching experience and pedagogy to inspire and encourage the development of more nature-based biomimicry first-year seminars that spread interdisciplinary biomimicry education to other liberal arts and sciences institutions.

Institutional Background

The College of Charleston is a comprehensive, public, four-year, liberal arts and sciences, state university founded in 1770 located in Charleston, South Carolina, USA. Known for its teacher-scholar faculty and world class undergraduate research, the urban campus educates about 10,000 students from approximately 45 states and 32 countries, with a low faculty to student ratio (14.5:1) in a beautiful small college atmosphere. The student population is

approximately 16% domestic students of color and 2% international (College of Charleston, n.d.a.). In-state students make up slightly more than half the undergraduate population. Campus life is intertwined with both natural and city landscapes. Picturesque live-oak-lined brick pathways draped in Spanish moss and blooming greenspaces adorn the historic campus that is a short stroll from Charleston Harbor where dolphins, pelicans, oysters, herons, and an expansive salt marsh ecosystem generate a tidal rhythm in daily downtown life.

Carleton College is a private, residential, four-year liberal arts and sciences college founded in 1866 in the small, river town of Northfield, Minnesota, USA. Carleton serves just over 2,000 undergraduate students through a variety of course offerings with a low faculty to student ratio (9:1). As of 2017, the student population was 26.5% domestic students of color, 10.9% first generation, 83.5% U.S. citizens from out of state, and 10.2% international (Carleton College, n.d.a.). Campus life is lively with a wide variety of structured and unstructured extracurricular opportunities. The picturesque campus is dominated by green space and is adjacent to an 800-acre arboretum of restored prairie and forest habitat, which is used for research and recreation by members of the college and the local town.

Carleton College and the College of Charleston both require incoming students to enroll in a first-year experience. Though students choose from a variety of topics, all the seminars or learning communities at each of these liberal arts and sciences colleges aim to achieve a shared set of objectives: (a) prepare students for college level reading, research, writing, and discourse; (b) integrate first-year students into the academic and cultural community; and (c) instill the meaning and value of a liberal arts and sciences education (Carleton College, n.d.b.; College of Charleston, n.d.b.). Our seminars were small by design, with 20 or fewer students. The CofC seminar has been offered to a general first-year audience each fall from 2016 through 2020. The Carleton seminar was offered in the fall 2019 and was chosen as the FYE seminar for that year's cohort of FOCUS (Fostering Careers in Science) students (Carleton College, n.d.c). As such, it had heightened representation from international and BIPOC students compared to the average Carleton classroom.

Human subject research originated with students at the College of Charleston. All student quotes and artifacts included in this manuscript are exclusively from College of Charleston students and are IRB approved. *IRB-2020-06-04-183355-a-2020-07-21-123012 - Exempt Protocol Modification Analysis of FYE student artifacts.* The contribution from Carleton College represents the instructor's observations and reflections on the curriculum and its effectiveness. Carleton College normalizes reflecting upon course development and high-level impressions of impact on students in order to iterate pedagogy without IRB approval.

Description of Curricula

So many of society's challenges stem from our misalignment with the natural world. Humans are a part of nature, and the Earth is our only home. However, our modern western mindset of separation from and superiority over nature contributes to our linear, extractive, colonial economy and destructive, disposable, unsustainable lifestyle. Increasingly, problem solvers are realizing that insights from nature can serve not just as a source of innovation, but also promote life-sustaining resilience. The natural world has already solved many of the same challenges humans are currently grappling with, often with more elegant and multifunctional tactics that use less energy and material (Hayes et al., 2020; Vincent et al., 2006).

The practice of learning from nature takes many forms. Biomimicry – and the related practices of bionics, biomimetics, and bio-inspired design – is an emerging multidisciplinary approach to innovative problem-solving that seeks to emulate functional biological adaptations in order to inspire more innovative, efficient, resilient, and regenerative solutions to human problems (Bar-Cohen, 2012; Benyus, 1997; Hayes et al., 2020; Singhal et al., 2020). Practitioners of biomimicry realize that when striving to solve a problem, one of our first questions should be "What would nature do?" Though the foundation of biomimicry lies within biology, the process merges with engineering, design, and other disciplines such as chemistry, architecture, urban planning, social innovation, and business to emulate the way nature functions, not just the way it looks. Students and practitioners of biomimicry don't just learn about nature, they learn from nature, cultivating a sense of awe for the wonders of the natural world. From bullet trains emulating the kingfisher bill to concrete that sequesters carbon like a coral reef to cities that behave like forests (Singhal et al., 2020), biomimicry is taking off with surges in related scientific research and patent applications (Hayes et al., 2020; Snell-Rood, 2016). Biomimicry differs from other nature-inspired practices because, in addition to seeking technological advancement and sustainability outcomes, it prompts us to consider our interdependence with the rest of life, cultivating reconnection, humility, and respect (Baumeister et al, 2014; Benyus 1997; Kennedy et al., 2015)

Our independently designed, experiential curricula share the overarching goal for our students to leave our courses (a) having successfully begun their transition to the liberal arts and sciences undergraduate setting, (b) relating more strongly to the natural world, (c) drawing inspiration for human problem-solving from nature, (d)

questioning the perspectives and assumptions they brought with them to class, and (e) thinking more critically and holistically. Though our seminars may vary in specifics, they converge on similar learning objectives, topics, and pedagogical approaches. Three major themes characterize our seminars and were run in parallel throughout the term: nature journaling excursions, nature-inspired problem-solving, and conceptual exploration. These three themes align with the three essential elements of biomimicry described by Baumeister (2014): (re)connect, emulate, and ethos. The element of "(re)connect" encourages fostering an understanding of our relationship to and interdependence with the rest of the natural world. It is written with parentheses to emphasize the experience of relating to the natural world may be either a reconnection or a connection, depending on each individual's previous experience. Though this has an intellectual component, the real transformation occurs when an individual is interacting directly with nature, whether a small object or a large landscape. Engaging with the natural world in such an intentional and holistic way breaks down artificial barriers between people and nature and illuminates the dualistic thinking that creates them. As a consequence, participants often increase their humility and respect for the rest of life. The element of "emulate" is most closely aligned with nature-inspired problem-solving and is often used interchangeably with terms like biomimetics, bionics, and bio-inspired design. It is the transfer of knowledge embedded in biological forms, processes, or systems into a given problem-solving discipline, whether engineering, chemistry, architecture, or urban planning. The element of "ethos" highlights an intentionality to be responsible to our non-human co-inhabitants and the Earth as our only home. This ethic of centering the interests of all biodiversity differentiates biomimicry from other bioinspired practices by placing priority on generating outcomes that contribute to sustainable living and ecological alignment over the long haul (Stevens et al., 2019). Taught together, these three themes of relationship to nature, inspiration from nature, and responsibility to nature create not only an interdisciplinary experience but also one that provokes deep personal introspection, growth, and change within our students. These characteristics make such a course ideal for students in transition from high school to university life.

Overall, our seminars focused on application of knowledge rather than fact-based learning, a theme within biomimetic curricula (Wanieck et al., 2020). An advantage of this student-centered, skills-focused approach is that students are able to take their learning with them regardless of what course of study they pursue next. In addition to equipping students with skills, we sought to empower students to uncover misconceptions, welcome surprise, brainstorm freely, question abundantly, and play frequently. We used inclusive imagery and language, with conscientious awareness of gender bias. What had always been an inclusive pedagogy became actively anti-racist in 2020 (Kendi, 2019). Randomized seating and frequent low stakes sharing opportunities strived to create learning spaces in which students developed self-efficacy and created community to promote a growth mindset and greater appreciation of diverse perspectives. Our instruction encouraged metacognition to help students learn how to learn using cognitive psychology, including repetition and retrieval practices with interleaving (Brown et al., 2014). To build higher order thinking skills, we used applied learning scenarios and experiential learning. We provided ample opportunities for students to collaboratively explore, explain, elaborate, apply, analyze, evaluate, and create new knowledge, using the 5 E method linked to Bloom's taxonomy (Bloom, 1956; Bybee et al., 2006). Regular self-reflection exercises created space for students to digest new perspectives and to mold their shifting mindsets as first-term undergraduates adapting to a new environment while simultaneously figuring out future studies and career paths. Students were encouraged to turn their learning into personal action in the short term, whether by engaging in activism, organizing, problem-solving, or personal change. Most of all, they were prompted to self-reflect on how they might fit into a world of interdisciplinary work and how a liberal arts and sciences education can set them up for success over the long-term.

Nature Journaling & (Re)connect

Observing the natural world is a critical skill for a biomimic, serving not only as a source of inspiration but also as an opportunity to be in relationship with the rest of life. Students were tasked to regularly immerse in their local natural environment and complete nature journaling assignments. Recording these natural history field notes compelled students to practice the skills of observation, attention, and description. Importantly, students were able to explore their surroundings, unplug from campus life and electronic devices, and let their curiosity roam. This nature journaling theme centered the element of (re)connect by getting students to be outside in personal interaction with nature.

For each assignment, students were asked to spend at least 45 minutes in nature responding to an assignment prompt that resulted in their submitting an annotated illustration and reflection (Figures 1 & 2). For most assignments, they were prompted to choose a spot to sit and observe a particular subject of their choice. This could be an expansive vista, patch of habitat, an organism, or part of an organism. Their goal was to be still, quiet the mind, and open their senses to allow the subject to reveal itself. We encouraged them to observe

Figure 1
Example of Student Nature Journaling / (Re)Connect Assignment: Monarch Butterfly Forewing Illustration with Annotations

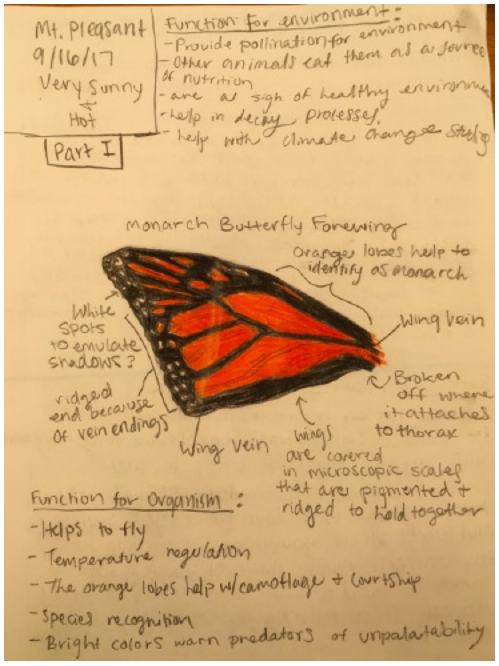
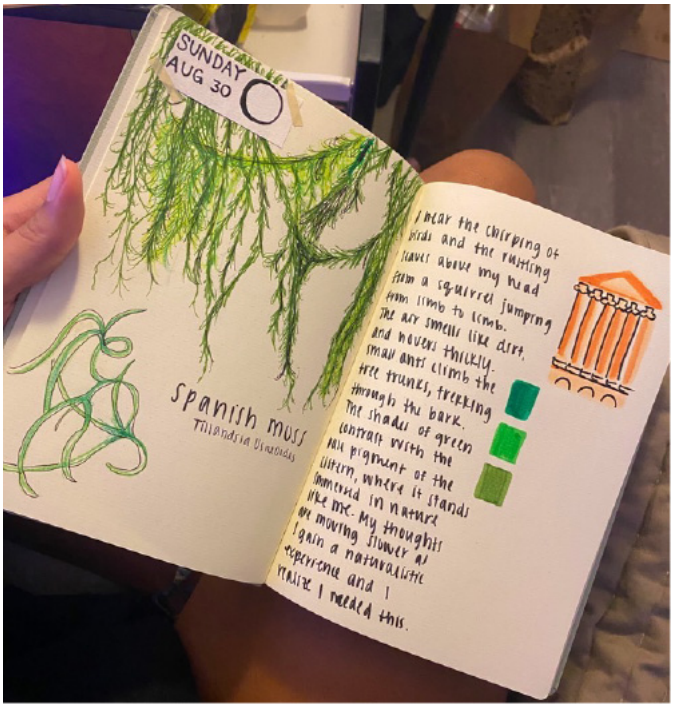


Figure 2
Example of Student Nature Journaling / (Re)Connect Assignment: Spanish Moss Illustration with Annotations



without jumping to conclusions, notice without judgement, and capture what came to their mind. Weekly prompts varied according to course content, generally encouraging students to apply certain skills and tools learned in class, reflect on ideas related to course readings and discussions, and make space for the unexpected. Many of our prompts were adapted from *iSites: Nature Journaling for Biomimicry* (Rovalo, 2019). Sharing, discussion, and peer feedback targeted collaborative learning. When evaluating student nature journaling work, our focus was not on their artistic aptitude. Rather, we sought evidence of thoughtfulness characterized by signs of investment in the experience, detailed annotations, and genuine reflections. The process is more important to the learning than the aesthetics of the illustration (Kang et al. 2014; Rovalo, 2019), and it was much more important for students to share their questions, pondering, thoughts, and comments.

We sought to create an opportunity for our students to cultivate a stronger practice of observation, attention to detail, asking deeper questions, and following their curiosity. It has been shown that natural history instruction is more successful when students explore and make their own observations, capture, and communicate these observations, and achieve an understanding of place (Farnsworth & Beatty, 2012; Fleischner, 2011; Gilligan, 2009). In seeking inspiration from the natural world, the practice of biomimicry requires both scientific accuracy as well as imaginative creativity. Drawing in science and natural history serves various purposes in student learning: drawing as a mode of internalizing science, drawing to enhance observation, drawing to enhance model-based reasoning, drawing for problem-solving, drawing to connect concepts/ideas, drawing to learn, drawing to reveal students' mental models, and drawing to communicate (Quillin & Thomas, 2015; Stevens et al., *in press*). Drawing enables students to synthesize complex ideas and elucidate where questions and gaps in their understanding may remain (Quillin & Thomas, 2015; Van Meter et al., 2006). Drawing scientific visualizations can improve curiosity, understanding, and communication, and it is an important learning aid for science educators (Landin 2015; Merkle 2018; Pyle, 2000; Stevens et al., *in press*). Thus, these nature journaling assignments were a method for students to learn about biology and enhance their creativity for applying biological inspiration to problem-solving. Importantly, these skills carry value far beyond biomimicry and are transferable to whichever course of study our students pursue next.

Beyond scientific understanding and creative problem-solving, we expected that these experiences would support our students' affinity for the rest of life by strengthening their biophilia (Wilson, 2010), deepening their sense of place and their value of their surrounding natural landscapes and the life forms that inhabit them. They can also contribute to personal growth, wellbeing, and comradery. The solo nature journaling and group class outings aimed to foster student wellness by decreasing stress and increasing mindfulness, self-awareness, focus, and serenity. Class socials, field trips, outdoor lessons, and exposure to nature areas on campus aimed to create mutual shared experience that develops relationships, fosters trust, and improves group dynamics, resulting in a heightened sense of belonging and allowing for more successful team-based projects.

Nature-Inspired Problem-Solving & Emulate

Biomimetic design incorporates lessons from biological forms, processes, and systems to create solutions to human challenges while also supporting the life support systems of our planet. This process is captured by the element of emulate. Humans and the rest of nature operate in environments with similar biological and physical contexts, constraints, and boundaries. Through evolution by natural selection, species have become adapted to function effectively in their given ecological context. Biologically inspired problem-solving generally seeks to learn from these traits with the goal of informing human decision-making and developing more innovative and effective human creations. In addition to being more innovative, biologically inspired creations have the potential to be more resilient and sustainable through their circularity, multifunctionality, and reduced use of energy and material (Vincent et al., 2006).

Though nature-inspired solutions have often occurred because of serendipity (Harman, 2013), there has been an increased interest over the last couple decades to intentionally learn from nature (Lepora et al., 2013). The majority follow the same series of steps, generally beginning with problem analysis, followed by biological research and interpretation, and completed with transfer and implementation; at least 40 tools have been developed for various stages of this workflow (Wanieck et al., 2017). In order to become familiar and gain practice with this process, our students participated in a term-long assignment that engaged them with one particular tool, Biomimicry Thinking, which is part of the *Biomimicry Toolbox* (Baumeister et al., 2014; Biomimicry Institute, n.d.a.). Our assignments were structured around vexing socio-environmental challenges identified by either the UN Sustainable Development Goals (UNSDGs; United Nations, n.d.) or Project Drawdown (Hawken, 2017), a nonprofit spotlighting challenges and corresponding solutions to address atmospheric greenhouse gas levels. Examples of broad challenges included sea level rise, extreme weather events, food security, access to clean water and air, equitable education, energy production and

distribution, transportation, packaging, and materials manufacturing. Students were grouped into teams based on their expressed interests and tasked with applying the Biomimicry Thinking process. Generally, this included analyzing their challenge, adapting their question(s) for the biomimetic process, discovering relevant biological models, interpreting their results, and applying that knowledge to brainstorming creative solutions. Biomimicry Thinking can be used in multiple ways but often follows the specific sequence of *scoping* the challenge, *discovering* existing natural solutions, *creating* design ideas inspired by nature, and *evaluating* them based on life's principles to create innovative and more sustainable designs (Baumeister et al., 2014; Biomimicry Institute, n.d.a.).

The first step in the Biomimicry Thinking process is called scoping, i.e., problem analysis. Properly understanding a challenge is paramount to any kind of successful problem-solving process and especially one based on bio-inspiration. We taught our students to take a systems thinking perspective (Meadows & Write, 2008) when analyzing a complex problem or challenge (Figure 3). This process included asking the following questions: What system(s) is my particular topic of interest nested within? Who are the stakeholders? What are the elements, interconnections and functions of these systems (i.e., stock and flows)? What amplifies or diminishes what I seek to achieve (i.e., feedback loops)? Where in this system is the most effective place to intervene to affect change (i.e., leverage points)? In order to move beyond the symptom of a problem and understand its root causes, our students practiced asking "why" multiple times (Figure 4); each answer became the basis for further inquiry (Ōno, 1988). Being able to move past the superficial symptom and see the underlying challenge and larger system is a skill applicable far beyond the practice of biomimicry. In this way, our curricula equipstudents with tools necessary for any interdisciplinary work.

In order to effectively and efficiently find biological models relevant to a particular challenge, students must reframe their challenge in a way that can match the context and language of biology. This is done by focusing on what we want our design to *do* rather than what we want our design to *be.* For example, instead of asking, "How does nature make a wind turbine?", we might rephrase the question as "How does nature increase thrust?" or "How does nature reduce drag?" Such phrasing that focuses on function allows for a more effective transposition of the human challenge into the biological space (Baumeister et al. 2014; Bhushan, 2009; Biomimicry Institute, n.d.b; Cohen et al., 2014). When using the language of function to describe the world, parallels begin to emerge between human design and biology. Another benefit of looking at challenges through the functional lens is that it encourages students to be more curious and creative in exploring a problem without jumping too quickly to a particular solution (Baumeister et al., 2014).

Equipped with a comprehensive understanding of their challenge and a functional phrasing, our students then turned to finding, understanding, and interpreting biological forms, processes, and systems that hold promise of inspiring novel and more sustainable solutions. This is the second step in the Biomimicry Thinking process and is known as discovery. Students focus on finding potential mentors using the functional and contextual information they identified during the scoping phase. Their work begins with brainstorming research leads through web searches, discussions with peers, consultation with their instructors, and time spent interacting with natural objects (e.g., nature journaling). Schuknecht, 2014).

Figure 3

Example of Student Systems Mapping Using Systems Thinking: Stocks, Flows, and Feedback Loops

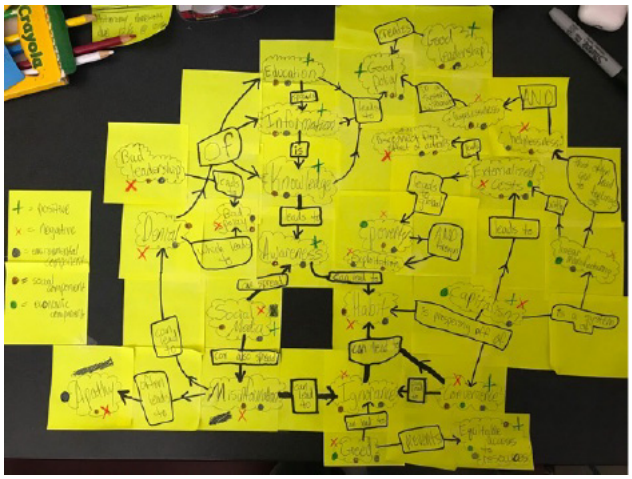
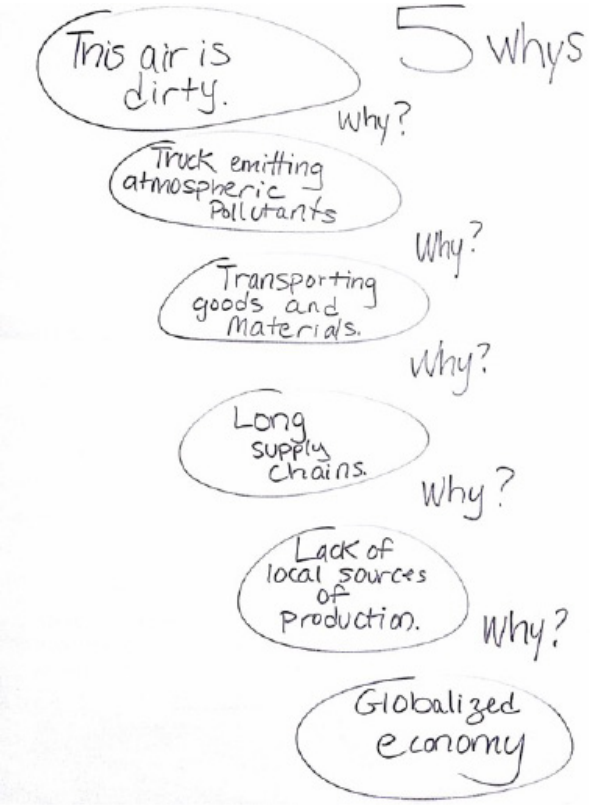


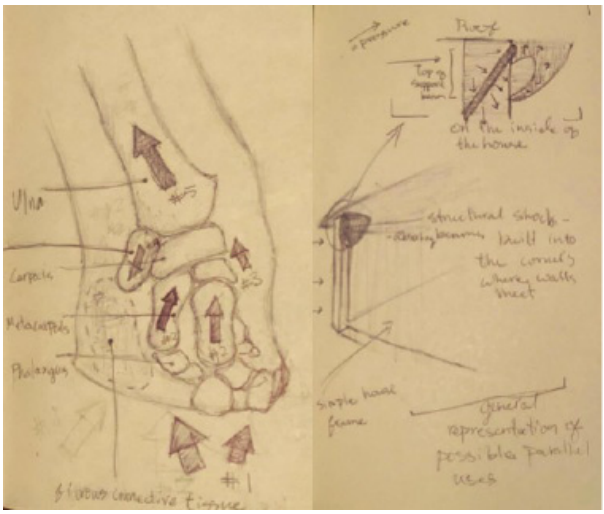
Figure 4
Example of Systems Thinking Using 5 Why Process



The biomimicry website AskNature was a valuable teaching and learning tool (AskNature, n.d.; Delden &

Having identified a broad, diverse list of potential candidates, students must exercise judgement and use their own criteria to refine their list to a handful of top choices which they will investigate further. Here, students engage with available primary and secondary scientific literature in order to understand how the biological trait works and achieves the desired function. By the end, students are expected to deliver a summary that includes relevant natural history background, a description of the function, strategy, and mechanism, and a distillation of the biological lesson that is free of biological jargon and most relevant for the creative phase of the process. For example, one of our teams tackled the challenge of improving structural integrity of housing in hurricane winds. Their scoping process keyed in on the functional question "How does nature maintain physical integrity and protect from abiotic factors such as wind?" Using this as their search lens together with selection criteria, they discovered that the African elephant (*Loxodonta africana*) maintains its immense body mass while protecting the tissue and structures of its weight-bearing appendages. Elephant feet mitigate damage by passively distributing pressure up the leg, alleviating

Figure 5
Example of Biological Mechanism Translation, Emulation, and Application



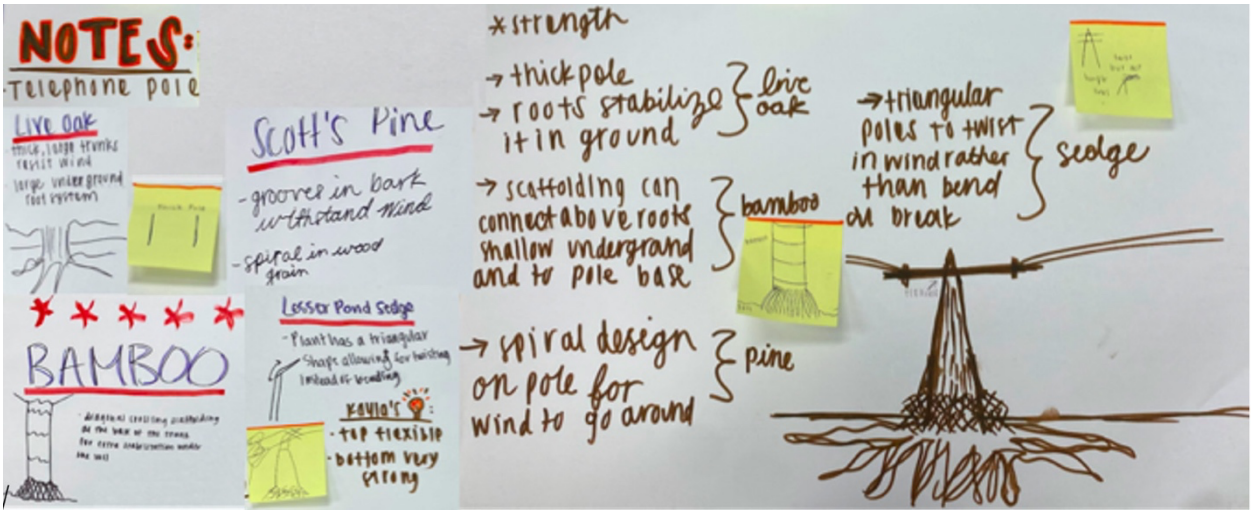
localized stress (Panagiotopoulou et al., 2016). One deliverable of this assignment included a written description along with illustrations demonstrating their understanding of the mechanism (Figure 5).

Students were encouraged to apply the lessons learned from this exploration to brainstorming possible solutions. Ideas were supposed to be plausible but need not be held back by practicality. This was a playful and low stakes opportunity to create. Students were expected to take intellectual risks and had freedom to fail (Figure 6). This was our students' opportunity to experience the innovative mindset required in the create portion of the Biomimicry Thinking process while working within the constraints of time, past experience, and technical expertise. Student teams completed their assignment by communicating their learning through visual, written, and oral presentations (Figure 7).

Conceptual Exploration & Ethos

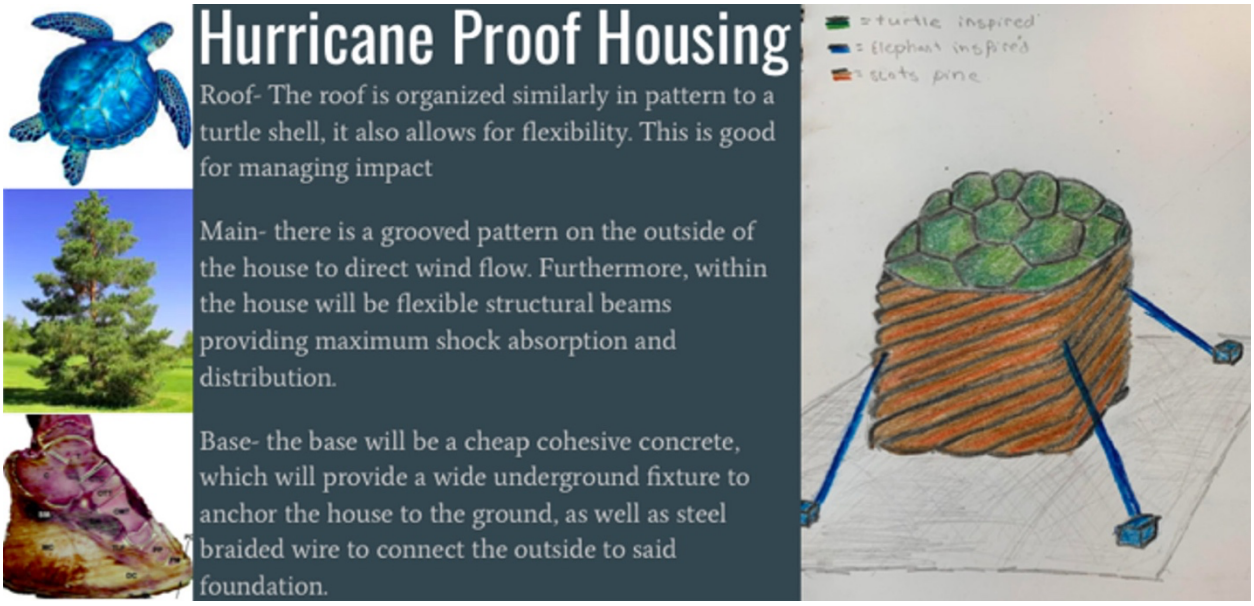
The goal of biomimicry is to guide our species into ecological alignment with the rest of the planet to live in ways where our impact on the world creates conditions conducive to life (Benyus, 1997) rather than in a way that degrades the planet's life support systems. To achieve such a future requires more than just advancement of sustainable technologies. Because sustainability challenges are linked to how our society is organized, what we value and what we prioritize, we must explore our values, our incentives, and our culture. The element of ethos helps facilitate this exploration and the creation of a life-centered ethic.

Figure 6
Example of Brainstormed Emulation of Natural Structures to Inform Telephone Pole Design



This conceptual exploration drew on scholarship in philosophy, ethics, political science, environmental history, economics, systems thinking, and indigenous thinking. Authors such as Benyus (1997), Cronon (1996), Kellert (1993), Kimmerer (2013), Meadows (1999), Owen (2012), Suzuki (2003), and others challenged students with under-explored viewpoints, alternative perspectives, and varied conceptual frames of reference. We strived to stimulate cognitive dissonance, allowing students to uncover and interrogate their presuppositions and to question their underlying assumptions about environmentalism, politics, economics, technology, and what it means to live sustainably or to learn from nature. We intended for our students to come away with a broadened notion of sustainability that goes beyond harm mitigation to making positive impact and healing past damage. Moreover, we wanted students to self-reflect on their participation in these systems as well as how they show up in the world through their values and actions. We challenged students to create eco-futurist views that envision living in alignment with the natural world and examine what is required to manifest their vision.

Figure 7
Example of Prototyped Emulation of Natural Forms to Inspire Hurricane Proof Housing



Systems thinking was a focus of this exploration. To contextualize complex issues students read "History of a Cup of Coffee" (Durning & Ayres, 1994), an article which looks at the complex global system required to generate a cup of coffee in the United States, exploring the outsourcing of social, environmental, and economic (triple bottom line) impacts and the resulting disconnect between the product and the story of its production and distribution. Excerpts from "Thinking in Systems" (Meadows & Wright, 2008) urged students to consider how systems can be leveraged to stimulate change and where there are opportunities to intervene – from implementing simple metrics to changing paradigms. Students applied this approach to large and small problems and began to see the world in systems. One particularly successful activity had students name a challenge, which we wrote in the middle of the board. To the left, we wrote out the answers to a lot of why-questions about why a particular challenge existed. For example, we might start with air pollution and realize that this is caused by traffic, which is driven by a need to commute in personal automobiles, which is driven by a system that requires commuting, which in turn might be connected to a lack of local affordable housing. To the right, we wrote out the answers to a lot of why-questions about why a particular challenge that exists is a problem. In this case, increased air pollution leads to detrimental impacts on human and environmental health.

Students addressed how sustainability is, at its heart, a human behavior challenge. We discussed how challenging it is to change minds and considered that the evolution of the human brain for survival favors emotional decisions over analytical ones (Kaplan et al., 2016). Students leaned into empathy and team building techniques that can build cross cultural unity and prevent social isolationism. Next, they considered that changing minds does not equate to changing behavior. The role of leverage from top-down policy drivers and bottom-up grassroots initiatives to drive the incentivization of behavior change or systems change was examined.

Individual final projects aimed to have students synthesize their course learning and explore a topic of personal interest that related to broad perspectives of sustainability and promoted an interdisciplinary perspective. Students were encouraged to bring together material from various elements of the seminar. Topics varied across years and semesters; some projects focused on the role of personal responsibility, the interplay between biomimicry and other environmental paradigms, a systems map merging a triple bottom line perspective with a biomimetic perspective, and descriptions of the potential positive impacts of a proposed greenspace in a rapidly gentrifying formerly redlined section of a city. Other students have crafted art installations, children's books, posters, letters to the editor, oral presentations, articles for the student literary magazine, and other creative synthesis-oriented deliverables.

Outcomes, Reflection and Discussion

Assessment of student assignments and reflections reveals strong evidence (Table 1-3) that course objectives (Table 4) in both biomimicry and the first-year experience were met or exceeded. Merging the first-year seminar and biomimicry pedagogies seems to create an amplification of learning in both areas (Table 4).

Students commented that field trips and nature journaling were beloved components of the course. Nature journaling allowed students to get to know their new campus homes from a natural history perspective. Students' observations in nature improved STEM fluency and appeared to lay the foundation for critical thinking through observation, interpretation, inference, and analysis (Figure 1). They also prompted bonding to nature on campus (Figure 2), increasing biophilia, which may reinforce first-year students' sense of belonging, primarily formed through social bonds with peers and faculty in more typical first-year experience courses (Chaffin et al., 2019). Students noted feelings of attachment to the non-human organisms on campus, noting recognition of individual organisms and sensations of being "home" (Table 1). This biophilia and greater appreciation for biodiversity builds empathy in human-nature interactions. The increased curiosity and inquiry generated by nature journaling can amplify lifelong learning skills and autonomy. Students noted a desire to take their nature learning with them and apply it in their day to day lives as well as in their other courses (Table 1). Field excursions in inclement weather may increase resilience and personal responsibility, fostering coping and adaptability. The self-awareness, mindfulness and serenity discovered while nature journaling (Table 1 & 2) catalyze behaviors that improve long-term personal resilience and wellness, particularly vital during the 2020 pandemic (Rousseau & Deschacht, 2020). Developing observational and nature journaling skills over time and reflecting on improvement allowed students to nurture an iterative, growth mindset. For example, whereas at the start of the semester students may have expressed an inability to draw, by the end of the term they were more likely to express progress in their drawing and observation skills. Field trips (Table 1) and nature journaling (Table 1) allowed for relationship building and bonding between students, peer mentors, and faculty, likely through mutual shared experience (Goodwin, 2020; Itin, 1999; Sancho & Bidwell, 2014). Excerpts of student work (Figures 6 & 7; Table 2) shows evidence that incorporating art into STEM education creates transdisciplinary STEAM thinking, opening up new ways of thinking and seeing, and developing solutionary thinking

Table 1
Excerpted Student Course Reflections

"...adventuring out into nature and exploring, discovering new things, was actually quite enjoyable for me, especially with the unfamiliarity of a new place."
"I felt noticeably calmer and happier than I had been… especially after being stuck inside classrooms.... I also felt surprised at there being such a secluded piece of nature right in the middle of campus."
"For some reason, I now feel really attached to this tree. I feel like it is my tree. I feel a connection to it. I sat there and inspected this tree for at least an hour. My eyes wandered every inch of the tree that I could see."
"Field trips help us bond and feel more comfortable with our classmates."
"I am asked deep questions that really make me think about the effect nature has on us and that we have on nature… reminds me of the value that nature has and how dependent we are on it...."
"This method of drawing with your right brain rather than your left brain, truly opened my eyes to see how much more accurately I can see and draw plants."
"We have spent too long trying to civilize the natural world rather than learning from it."
"As I walk through the Cistern I get a real sense of home… the green landscape lightened my mood… what caught my eye most was the Spanish moss and how elegant it looks draped over the live oaks canopy."
"There tends to be a disconnect in thought and understanding when it comes to the importance of nature in our society, where we see it as a place we can 'go' as opposed to an environment we already exist in."
"Nature creates a more open culture reminding individuals that they are in fact a part of this system, and not superior to it as is commonly thought."
"I really want to take the information I have learned in this course with me in my daily life and in other courses."
"Finding peace in the quietness and beauty of nature, helps me see the things I need to do more clearly and has given me a better sense of time so that I can plan out my work better."
"Humans are in so much debt to nature that is often overlooked… Disconnection is the single most significant hindering factor of conservation in our generation."
"The ability to make us connect the outside world to what we learned in the class was very valuable...preparing us for not only future classes but also for potential worldly problems."

(Ghanbari, 2015; Guyotte et al., 2014). Reviewing student nature journals for this manuscript resulted in our updated nature journaling rubric (Table 3).

Through the nature-inspired problem-solving and emulation course components, we see clear indications that students developed their STEM fluency (Figure 5; Table 2.) They began thinking in systems and indicated increased empathy for the perspective of diverse stakeholders as they scoped out their challenges. They found and evaluated reliable information sources, including primary literature, and these deep dives into the research were autonomously motivated through curiosity and inquiry. Our first-year seminar students communicated about biology, engineering, environmental science, and sustainability in a variety of written, graphic, and oral formats. While working in teams, students reflected on their personal leadership strengths and blindspots. At the conclusion of these lengthy, scaffolded team projects, students also reflected on their challenges and successes with respect to time management, interpersonal communication, group dynamics, and intra-team conflict resolution. Bonding and resulting friendships were forged during these team projects (Table 1). Belonging and inclusion is enhanced

Table 2
Excerpted Student Work by Course Theme

Seminar Theme	Relevant Student Quotes
Nature Journaling/ (Re)connect	"As for the question on my drawing, I researched it and discovered that Spanish Moss propagates in two different ways: through seed and, like many other bromeliads, by producing pups, which are small copies of the plant that grow from an original. They spread around to other places through the wind and water, and the seeds are structured in such a way that they are easily blown by the wind." "Each and every plant is so different from one another and it can be only the slightest of details that differentiate one type of flower from the other." "Before going outside to complete my first Nature Journal, I felt stressed. Being in a new environment and acclimating to college was a lot to deal with, so I was rushing around constantly trying to find the balance between school, athletics, and social life. When I went to the Cistern and found the tree I wanted to sketch, I sat down and as the time went by, I felt a lot less stressed. Being outside and sitting in the silence, focusing on the tree made me feel much better. I wasn't focused on the amount of school work I had or how early I had to wake up the next morning."
Nature-Inspired problem-solving / Emulate	"...in New York City skyscrapers take up less ground space than my local costco. Instead of spreading out horizontally the buildings stretch way up, housing hundreds even thousands of people on merely one block. This is quite like how trees tower up and house many organisms. Trees have a multi-functional design as well; their leaves absorb sunlight, water, and serve as food for other organisms… Maybe our future buildings could do more good for their surroundings too..." "The European hedgehog has quills that point in a large variety of directions that can help lessen impacts from any direction. This is very helpful for when a hedgehog is climbing a tree and they fall. When they land, the strong but flexible and resilient quills act as shock absorbers that have a braking effect and the foam-like center of the quills keeps them from breaking or buckling…. How can we learn from this hedgehog and incorporate its impressive function to make cars, helmets, and any number of things built to withstand impacts even safer?" "Roses have thorns (prickles) that are close together to trap wind blown sand and reduce erosion. Humans can incorporate that idea into beaches and how to protect beaches and homes on the beach or other places affected by erosion. Humans can make sand dunes more dense to reduce erosion and trap the sand flying in the air."
Conceptual Exploration / Ethos	"We as a society dance around the issue of sustainability claiming that the solution is to live off the land. But in reality what needs to happen is an awakening. The model we have for sustainability is almost every natural thing but ourselves. Instead of pretending like we are above our environment we need to embrace its lessons and principles thereby being a part of its cyclical process. We are currently outliers and that needs to change." "Biomimicry can help..., but simply cannot do it alone. A complex set of solutions must be formulated to address the problems at hand. Government must impose taxes and regulations to keep consumption and waste lower. I believe that finding a solution… will require much help from a diverse group of individuals. In order to build a thriving society we must get a handle on our environmental impacts while maintaining a healthy economy. We cannot have one without the other. If the world at large keeps ignoring

climate change and pollution, there inevitably will be no economy left for our politicians to worry about."

"One of my goals in life is to help reconnect the grossly technology-obsessed and urbanized people of the world back with the magnificent natural realm of life. City streets, iPhones, and many other human advances have worked double time to deteriorate and eliminate humankind's relationship with nature. Given sufficient funds, I would work to implement more green and natural areas throughout urban cities to provide those stuck inside monotonous cubicles, tiny apartments, and suffocating cab cars a sanctuary in which they can relax and reconnect with the natural side of life."

by effective teamwork and may amplify students' growth mindset. This enhanced inclusivity is particularly vital for welcoming and retaining BIPOC students and women as they contemplate careers in STEM disciplines (Museus & Quaye 2009; Tovin-Lindsey et al., 2015). We wonder whether our students' newfound appreciation for nature as a mentor opens them up to learning from those they might otherwise dismiss.

The creativity demonstrated by student brainstorming and nature-inspired problem-solving exceeded our expectations (Figures 6 & 7; Table 2). Students were encouraged to iterate and consider applying their brainstormed ideas towards student led change-making on campus through application for changemaker green funds grant initiatives or entrepreneurial student competitions. Students practiced analogical thinking (Figures 5-7) by applying what was learned in one context, such as biology, to another context, such as design (Casakin & Goldschmidt, 1999; Stevens et al., 2020). Their intersectional solutionary thinking fostered eco-futurist views that stoke personal and political engagement and may create positive feedback on systems thinking skills, amplifying their discovery of leverage in systems and the desire for paradigm shifts that challenge the status quo (Table 2).

Table 3
Nature Journaling Rubric

Objectives	Themes	Evidence Criteria
Observation	Observation and increased attention to day-to-day surroundings and natural environments.	Students notice fine scale detail, broader patterns, change over time, differences between environments.
Curiosity	Curiosity for what is seen, posing questions, expressing desire to learn more.	Students ask questions, wonder "out-loud," identify unknowns, express a desire to seek or gain appropriate knowledge.
Insight	Demonstrating new connections, new perspectives, or sharing realizations based on nature journaling experience.	Students share insights, realizations, "ah-ha" moments, identifying connections between previously unconnected concepts, exhibit new perspectives.
Value	Form or strengthen an appreciation of and connection to the natural world.	Students indicate increasing awe, humility, gratitude, empathy, wonder, respect for the natural world.
Well-being	Pleasure and appreciation for being outside in the natural world – feelings of peace and relaxation.	Students share signs of relaxation, calm, joy, peace, serenity, pleasure – all related to being outside in the natural world.

Table 4

Summary of First Year Experience (FYE) and Biomimicry I(BMY) Competencies, Pedagogies, and Learning Outcomes

	FYE & BMY Pedagogies & Competencies		FYE & BMY Outcomes
Seminar Themes	High-impact Learning Methodologies	Liberal Arts and Sciences Skills	FYE and BMY Learning Outcomes
Nature Journaling/ (Re)connect	✓ Field trips and group dynamics ✓ Nature immersions ✓ Nature journaling ✓ Peer facilitation ✓ Peer feedback ✓ Reflexive learning	✓ Academic writing ✓ Biological illustration ✓ Field note taking ✓ Observation ✓ Questioning ✓ Seminar-style discussion	✓ Adaptability ✓ Appreciation of diversity ✓ Appreciation of nature ✓ Attention to detail ✓ Belonging ✓ Critical thinking ✓ Curiosity ✓ Empathy ✓ Growth mindset ✓ Mindfulness ✓ Resilience ✓ Self-awareness
Nature-Inspired Problem Solving / Emulate	✓ Brainstorming ✓ Collaborative team learning ✓ Peer facilitation ✓ Peer feedback ✓ Project/problem based learning ✓ Reflexive learning ✓ Research based learning	✓ Academic writing ✓ Applied problem-solving ✓ Brainstorming/ Design charette ✓ Graphic design ✓ Public speaking ✓ STEM primary literature research ✓ Thinking in systems	✓ Appreciation of diversity ✓ Autonomy ✓ Conflict resolution management ✓ Creativity ✓ Critical thinking ✓ Leadership ✓ STEM fluency ✓ Solutionary thinking ✓ Teamwork ✓ Time management
Conceptual Exploration / Ethos	✓ Challenging the status quo ✓ Cognitive dissonance ✓ Critical analysis ✓ Peer facilitation ✓ Peer feedback ✓ Reflexive learning	✓ Academic writing ✓ Discussion and inquiry ✓ Thinking in systems	✓ Appreciation of diversity ✓ Critical thinking ✓ Interdisciplinary thinking ✓ Personal and political engagement ✓ Self-knowledge

Ethos-related coursework focused on our underlying philosophy of nature and the human-nature connection. These exercises encouraged students to envision a future in which humans live in a way that not only does no harm, but actively cultivates good to promote healthy and resilient human societies in sustainable relationships with nature. Readings and discussions emphasized our interdependence with, dependence upon, and the respect owed for Earth's biodiversity. We see strong evidence that the ethos-centered course work stoked cognitive dissonance, and further stimulated students' critical analysis skills, particularly those relating to analysis, reflection, evaluation, and decision making (Table 2). Students frequently indicated a newfound realization that they are dwelling within a dysfunctional system. Their resulting shock, outrage, and frustration positively feeds back to amplify their creative problem-solving and solutionary thinking. Ethos centered curriculum also encouraged interdisciplinary perspectives and systems thinking. These skills, demonstrated by students through written and oral discussion and reflection, are vital for building self-knowledge and fostering personal and political engagement. Students are figuring out who they are and what they care about. This increasing self-knowledge and burgeoning activism may then positively amplify student belonging on campus through involvement in sustainability related clubs and activities. Club involvement can feedback to catalyze leadership and communication skills as well as solutionary thinking, amplifying further campus and community engagement.

Effective first-year seminars serve as the launch pad toward interdisciplinary higher-level thinking. They can frame and catalyze a student's entire liberal arts and sciences experience, priming students to ground and thrive in their new campus communities as autonomous meaning makers, lifelong learners, and engaged citizens (Cuseo 2009; Padgett et al 2013). Table 4 summarizes the competencies, pedagogies, and learning outcomes of our curricula. Our highly integrative biomimicry first-year seminar courses incorporated eight of the nine recommended best pedagogical practices for teaching sustainability, excluding only service learning, which we hope to work into future iterations of our post-COVID-19 courses (Evans, 2019). Overall, our biomimicry-themed first-year seminars resulted in strong potential for students to benefit from a powerful network of learning outcomes and nature journaling acts as a catalyst for creating positive feedback between first-year experience and biomimicry learning goals.

As the rate of anthropogenic climate change accelerates and our climate crisis becomes increasingly urgent, the number of students seeking degrees in sustainability and environmental studies is growing, especially at liberal arts and sciences institutions (Johnson et al., 2020; QS, 2019), and environmental educators must keep pace and adjust our teaching pedagogies. There has been a trend of both shifting from and merging between movements in environmental education. In the twentieth century, educators were shifting from nature conservation education (NCE) towards environmental education (EE) aimed at calling attention to environmental issues. Since then, we see shifting towards education for sustainable development (ESD) to include an intersectional triple bottom line approach to sustainability adding economic and social sustainability to the environmental piece and aiming to increase citizen engagement. Now we shift towards environmental and sustainability education (ESE) which builds on ESD by also emphasizing the interconnectivity and interdependence between humans and non-human life as well as stimulating agency and changemaking (Evans, 2019; Wals et al., 2017). Biomimicry is at the forefront of modern ESE, and our first-year seminars in biomimicry bring students into this discipline within the very first days of their college experience.

Conclusions

Our biomimicry-themed first-year experience curricula are multifaceted and achieve multiple levels of growth in our students. At one level, they expose students to a specific practice of nature-inspired problem-solving and sustainability. At another level, they equip students with skills that are transferable across disciplines and will serve our students no matter which path they pursue in their studies or their careers. Finally, our curricula promote self-exploration and questioning of world views in ways that facilitate personal growth and adaptability, traits very much needed in today's complex and changing world. These outcomes dovetail smoothly with the traditional goals of a FYE typical of most liberal arts and sciences colleges, promoting engagement, autonomy, and wellness, allowing students to thrive.

Our students are taking on leadership roles in campus sustainability organizations, engaging in sustainability internships, and developing their personal and political activism. Some students have contributed to biomimicry resources such as Ask Nature (AskNature, n.d.; Delden & Schuknecht, 2014). As they choose their majors and move into upper-level coursework, our students are personalizing their liberal arts and sciences educational experiences to develop the interdisciplinary skill sets and knowledge they need to meet their individualized goals. We are encouraged to witness their continued exploration and growth as nature lovers and changemakers. Several graduating students have pursued their STEM interests, sustainability related careers, as well as investigational research and sustainability graduate programs.

We note that an interdisciplinary upper-level undergraduate biomimicry thinking seminar course uniting biology, entrepreneurship, urban studies, environmental, and sustainability studies students has been taught twice at CofC beginning in 2018 and 2021 will be taught again in future years. Biomimicry seems to make a great course for interdisciplinary students transitioning from university into the workplace or graduate school as well as for those transitioning from high school to university. A pedagogical description of the upper-level integrated science CofC biomimicry course and the importance of drawing to abstract design principles can be found in Stevens et al (*in press*).

We conclude by encouraging the merger of biomimicry and first-year experiences at other liberal arts and sciences colleges and universities for students in transition, and we recommend the addition of a service-learning component (Evans, 2019) when possible. When it comes to teaching environmental and sustainability courses to interdisciplinary students in transition, don't forget to ask, "What would nature do?"

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