Assessment Report:

Student Engagement and Attitudes in the RISD BioDesign Classroom

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Author Note:

1. This is a report to assess the outcomes of the implementation of the BioDesign curriculum at the RISD Nature Lab. Any opinions, findings, conclusions or recommendations expressed are those of the author and not the collective research team.
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1. Introduction

Traditional science, technology, engineering and math (STEM) teaching positions teachers as the holders of knowledge in a way that contributes to conceptions of STEM field education as a homogenous set of epistemological practices that often fail to engage students (Nasir, Scott, Trujillo, & Hernández, 2016). Shifting the way STEM content is taught is considered critical to an agenda focused on raising the number and quality of students interested in and prepared to go into STEM fields (Markowitz, 2018; National Research Council, 2014). Transformative practices that seek to counter traditional notions of what STEM education can be center student's capacity to formulate and research questions of personal interest and see value in their own way of knowing and experiencing the world (Calabrese Barton & Tan, 2018; Vossoughi, Escudé, Kong, & Hooper, 2013).

This efficacy research study (*as defined in* NRC, 2014) investigates the impact of participating in a makerspace program focused on teaching a life science curriculum through an art and design pedagogy, situated in a uniquely designed *biophilic* classroom, on high school students' engagement in and attitudes toward science, as well as how students' experienced the program. Critical to this study is that it looks at what is happening outside the controlled environment of a lab and within the dynamic, lived context of the classroom. It adds to existing literature on student engagement in life science and offers insights into the potential of utilizing an art and design pedagogy in a transformative STEM (life science with an engineering focus) learning environment under ideal circumstances and support. The research question guiding the project is: *How does a nature-rich life-science curriculum, taught through an art and design pedagogy in a newly built BioDesign makerspace, appear to impact student engagement in and attitudes toward science content?*

2. Theoretical framework

2.1. Biophilia and Biodesign

Biologist E.O. Wilson (1984) first framed *biophilia* as the unconscious desire by human beings to be in relationship with nature (Wilson, 1984). Researchers from psychology to ecology, motivated by increased public awareness of the negative consequences of nature-deficient, sedentary indoor activity, offer empirical studies that demonstrate reconnecting humans with nature can have positive impact on the psychological and physiological well-being of young people (Kahn & Kellert, 2002; R. C. Moore & Marcus, 2008; Strife & Downey, 2009). Delineated among the findings are cognitive benefits, such as attention and focus, and academic outcomes (Berman, Jonides, & Kaplan, 2008; Faber Taylor & Kuo, 2009; Kaplan, 1995), as well as affective benefits such as prosocial behavior and decreased stress (Li & Sullivan, 2016; Zhang, Piff, Iyer, Koleva, & Keltner, 2014).

The field of biophilic design (BioDesign) prioritizes principles and practices that encourage the human-nature connection and promote potential health benefits (Kellert, 2015; Ryan, Browning, Clancy, Andrews, & Kallianpurkar, 2014) by integrating the sights, sounds, and forms of nature into children's learning spaces. In their study placing three plants in each three Year 6 and 7 classrooms versus control classroom Daly et al. (2010) found evidence of increases between 10% and 14% in spelling and mathematics tests (Daly, Burchett, & Torpy, 2010). A study in Taiwan with Year-8 students placed six plants in experimental classrooms versus control classrooms and found that the students with plant classrooms had immediate and significant stronger feelings of preference and comfort for their room, as well as less sick days and misbehavior reports than the control group (Han, 2009). Similar findings around preference were also supported by a study in the Netherlands, which additionally found that a small-scale intervention of a green wall (a vertical leafy plant installation) had positive impact on students' selective attention. A secondary impact of a living green wall is that it can also be used use for hands-on science experiments with children (Kazmierczak, n.d.). Despite promising qualitative and quantitative evidence, empirical work is still nascent in this field as designing long-term experimental studies with consistent methodologies proves very challenging in the lived situations of schools.

Exposure to nature and deepening the human-nature connection is also seen as critical to developing environmental literacy (EL), necessary to address some of the world's biggest environmental challenges. Stevenson (2013) found that while environmental education is important for all young people, it was especially impactful on Black and Hispanic youth (Stevenson, Peterson, Bondell, Mertig, & Moore, 2013). Studies also found that the lack of exposure to nature can breed *biophobia,* and an apathy toward environmental concerns which can potentially allow for continued systems of exploitation and destruction of nature (White, 2004).

2.2. Studio Pedagogy

Making with materials requires facilitation of classroom content and activities through a pedagogy that supports makers to begin with an initial research question or prompt and move towards knowledge through self-directed, teacher and peer facilitated, inquiry-based investigations, weaving together subject matter, imagination, and lived cultural experience (Burton, 2016; Gude, 2009; Marshall, 2014). In contrast to academic disciplines with defined end goals and systematized inquiry through directive, prescribed, and easily assessable steps, studio pedagogy encourages the development of learners that are flexible and holistic in their thinking, open to different ways of knowing, rely on the co-development of research directions and are internally motivated (Hetland, Winner, Veenema, & Sheridan, 2013; Morales, 2017).

Makerspaces utilize the pedagogy of the studio, explicitly or implicitly, as environments steeped in experiential learning theory that centers tools, personal-inquiry, and problem-posing (Chu, Angello, Quek, & Suarez, 2016; Halverson & Sheridan, 2014; Hira & Hynes, 2018). They bring together essential elements of a community and social space where members engage in interdisciplinary, interest-driven work that focuses on the process of making, and a mindset that welcomes feedback and failure, with the teacher in a facilitator and resource role. Makerspaces are being incorporated into schools as key places for integrated STEAM lessons (adding the Arts into STEM).

2.3. Engagement and attitude toward science

Student engagement, is generally understood as meaningful student participation and interaction within a classroom community (Fredricks, Blumenfeld, & Paris, 2004; Martin & Torres, 2017). In this study, engagement was defined through three, interrelated dimensions of (a) *affect*: feelings of enjoyment or positive or negative response to teachers or peers, (b) *behavior*: participation and time on task, and (c) *cognition*: investment in learning, perseverance, and transfer of ideas beyond the classroom (Fredricks & McColskey, 2012). Focus was also placed on student attitudes toward science, which are complicated through theories of interest and motivation (Appleton & Lawrenz, 2011; Germann, 1988; Green, Martin, & Marsh, 2007). Many students begin to form their disciplinary attitudes, as well as career interests, in middle and high school, making engagement a key construct to focus on during these years (Calabrese Barton & Tan, 2018; Saw, Chang, & Chan, 2018). A decline in interest in science is reported to begin as early as elementary school, with greater effects for girls, minoritized and low-income youth, or those with dual or triple underrepresented status (Saw et al., 2018).

3. Methods

3.1 Study Context

This project was a collaboration between a private art and design university, RISD, located in a small urban city of the Northeast, and a local alternative public high school, The Met, with an established relationship with the university. The Met's mission is to connect students with a life-long passion for learning by pursuing their interests in the real world. Adopting a personalized learning approach, The Met requires students to create extensive individualized learning plans which incorporate participation in internships and exhibitions with an adult mentor that tracks, documents and records progress on each student's plan. The 9-12 grade, mid-size city high school is Title I eligible, and serves approximately 800 students with 63% minority enrollment, and 72% qualifying for free and reduced lunch.

The larger research study was divided into three phases. In *Phase One*, the construct of BioDesign was examined by graduate level interior architecture students resulting in the design of a classroom which utilized key principles of biophilic space that emerged from their research. *Phase Two* involved the transformation of a designated room at the university into a "bio designed makerspace," utilizing the designs of the graduate students from the prior semester.

After the build out of the BioDesign makerspace, in *Phase Three*, pre-service teachers enrolled in the Art + Design MAT degree program co-developed a three-module curriculum to teach life-science principles related to biophilic design to explore biomimicry, biomaterials and biosystems, alongside their two faculty educators. The second implementation was taught by the research team biologist and a collaborating graduate student. Students from the Met traveled to the BioDesign classroom at the university once a week for ten weeks to participate in the program in both the Fall2018 and Spring2019 semesters. (Figure 1).

Figure 1. Images of one room of the Nature Lab and student researching using a light microscope

3.2 Study Participants

The high school participants that were the purposeful sample consisted of two cohorts of students from the Met. As shown in Table 1, 32 students participated in total in the two implementations of the study. Of those, 17 identified as Hispanic or Latino, 6 as Black or African American, 5 as White or Caucasian, and 1 as Native American or American Indian. All students, with one exception, were 15-16 years old and sophomores at the Met, and received parental permission to participate in the study through observation, video, photographs and interviews. 32 participating students participated in the qualitative data, and we used complete data sets from 22 students at for our statistical sample.

Table 1.
Demographics for participants in class with complete survey data

		age	#	gender	#	Race/ethnicity	#
FA18	class participants *n* = 17	15	12	Female	11	Hispanic or Latino	11
		16	5	Male	6	Black or African American	3
						Mixed Race	3
	complete survey data *n* = 10	15	7	Female	6	Hispanic or Latino	6
		16	3	Male	4	Black or African American	2
						Mixed Race	2

SP19	class participants *n* = 15	15 16 18	5 9 1	Female Male Other - *not specified*	10 4 1	Hispanic or Latino White/Caucasian Black/African American Native American/Am. Indian	6 5 3 1
	complete survey data *n* = 14	15 16	5 7	Female Male Other - *not specified*	7 4 1	Hispanic or Latino Black/African American White/Caucasian	5 3 4
Totals	class participants *n* = 32	15 16 18	17 14 1	Female Male Other - *not specified*	21 10 1	Hispanic or Latino Black/African American White/Caucasian Native American/Am. Indian	17 6 5 1
	complete survey data *n* = 22	15 16	12 10	Female Male Other - *not specified*	13 8 1	Hispanic or Latino Black/African American White/Caucasian Mixed Race	11 5 4 2

The five pre-service teachers enrolled in the MAT course represented a range of prior teaching experience and settings from community arts centers, museums and international educational environments. All were working to become certified art and design educators by passing the state licensure exam. They varied in age and work stage, from 1-10 years out of college. The curriculum, divided into 3 modules, had two pre-service teachers in charge of each module and leading the teaching each day, while the other three students provided more individualized instruction.

The biologist was a full-time employee of the Nature Lab and as the Biological Programs Designer, participates in research projects as her expertise is required or solicited; She was also a Co-PI on the project and very involved in obtaining the project grant. She is unique on the RISD faculty and staff in holding a PhD in a science field, and has also obtained certification in scientific illustration, spending time investigating the natural world through art. She has participated in multiple prior art/design + science projects in the past, generally given the role of scientist within those collaborations. She was the only RISD educator to participate in both implementations of the curriculum.

Similar to the pre-service teacher, the graduate student who was the main collaborator for the second implementation was enrolled in a MA program at the university with expressed interest in arts integration. After assisting from the periphery during the first implementation, she stepped into the role of co-teacher to iterate on curriculum from the first semester and teach alongside the biologist during the second semester. During the first semester, she acted as a second observer, lending her field notes to the observation data.

3.3 Curriculum Intervention

The curriculum consisted of a three-part study of life science aligned with both Next Generation Science Standards (NGSS, 2013) and the National Core Art Standards (NCAS, 2014). In the first unit, students focused on *biomimicry*, looking at the form and function of specimens found in the Nature Lab, and culminating in a design based on their chosen specimen. The second unit focused on *biomaterials*, offering students a chance to experiment with making and testing out various materials such as Kombucha leather and cornstarch plastics, and to develop a packaging that could replace a single-stream, plastic packaging product. The third unit focused on *biosystems*, in which students studied the efficiency and sustainability of natural systems and applied that understanding of cycles of resources and waste to design a solution to impact an urban, environmental or social system issue.

After completion of the first session with students, the co-instructors for the second session used interview and observation data to make small changes to the curriculum. The main changes were as follows:

1. “To limit the science "lecture" content, and try to weave the learning in a more integrated way into the activities

2. To define important vocabulary upfront, using vocabulary cards that were placed in their journals, as well as playing vocabulary games.
3. To include moments throughout the course where we spoke about design choices made in the room itself that reflected BioDesign considerations, such as sustainable materials, local organisms in the tanks and the functioning aquaponics units. (*email correspondence* 9.4.19)"

These were reflected in shared project Google Drive and iterated throughout the duration of the second implementations, with the graduate student co-instructor taking field notes on curriculum changes.

3.4 Study Method

The purpose of this study was to develop a better understanding of the potential impact and experience of students in a pilot program grounded in the human-nature connection and taught through an art + design pedagogy. A convergent mixed methods design was used (Figure 2) in which qualitative and quantitative data were collected in parallel, analyzed separately, and then merged for the two iterations of the program (Creswell & Plano Clark, 2018). The mixed method approach allowed us to examine whether the program may contribute to quantifiable gains in content knowledge, attitudes toward science and art, engagement and agency, and to corroborate or challenge those findings through qualitative data.

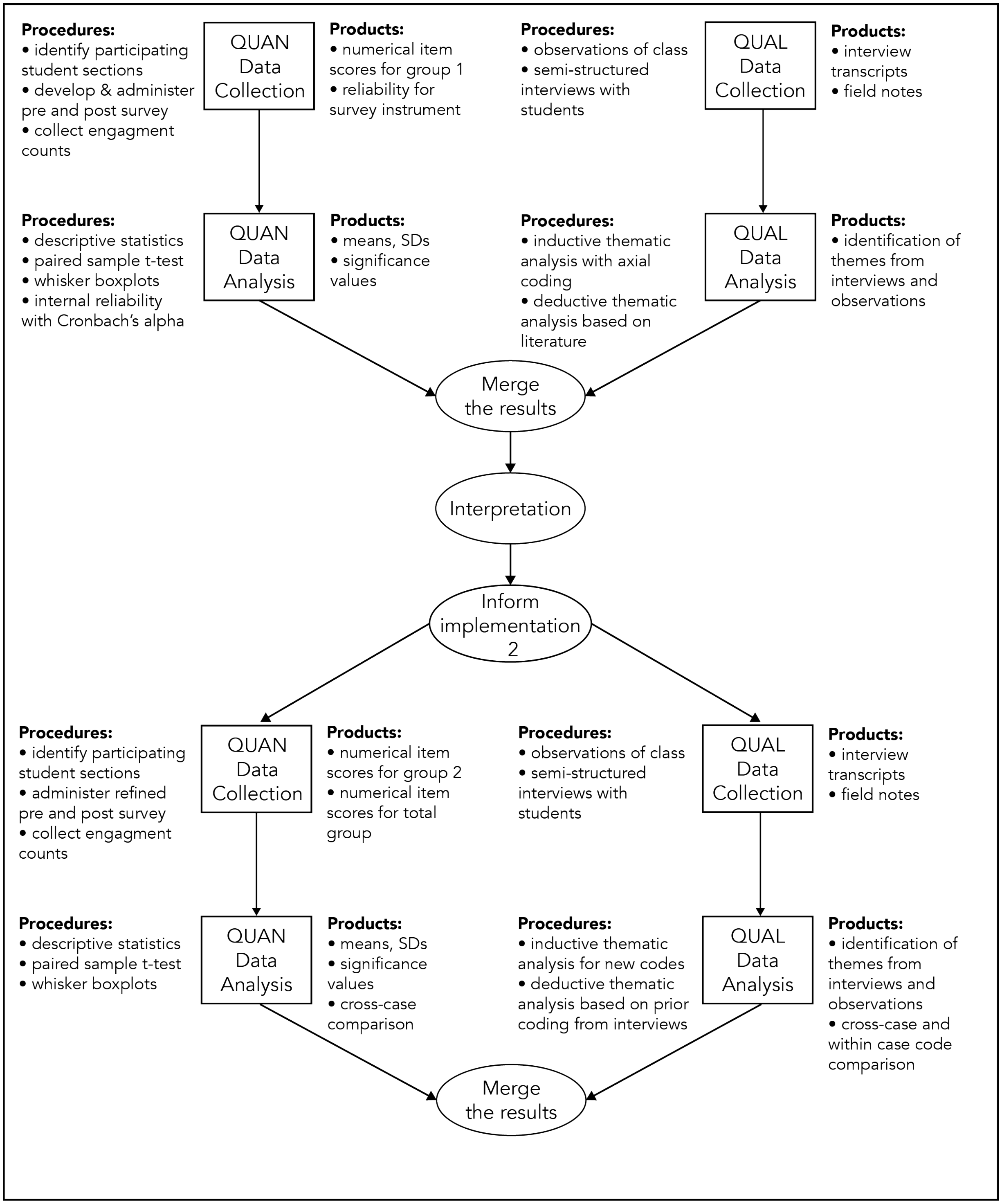


Figure 2. Diagram for convergent mixed method study design.

3.5 Quantitative data

Quantitative data consisted of pre-surveys taken before the program began and post-surveys taken after the last day of the program for the fall and spring implementations, administered through the Qualtrics platform. Items included 5-point Likert scale responses from 1 (strongly disagree) to 5 (strongly agree). The 42 item, pre-post survey instrument (Table 2 shows α for each dimension) was constructed from existing high-reliability Likert-scale instruments found in the literature that measure engagement, (e.g., *Most of the time I am focused on what we are learning during my science class*.) (Appleton & Lawrenz, 2011; Martin & Torres, 2017), attitudes toward science (e.g., *I am likely to sign up for a science class in the future.*) (Germann, 1988; Hillman, Zeeman, Tilburg, & List, 2016; Kier, Blanchard, Osborne, & Albert, 2014; R. W. Moore & Foy, 1997), and environmental agency (*I have the power to make on impact on the environment*). Each survey had science content questions related to the curriculum taught (e.g., *Matter and energy are transferred among producers, consumers, and decomposers in an ecosystem*.). Additionally, these question bases were used to construct additional items measuring attitude towards art and design (e.g., *I am likely to sign up for a design class in the future.*) and nature (e.g., *I am likely to seek out opportunities to be in nature.*). The post survey also included items related to the BioDesign space (e.g., *The classroom in which the program took place was an important part of the learning experience.*).

Table 2.
Reliability scores

	Cronbach's α (PRE)	Number of items
Engagement	.814	14
Biodesign	.722 (post only)	7
Attitude - science	.784	12
Attitude - art	.654	5
Agency	.549	4

Note: Attitudes toward nature contained only 2 items and therefore would not render a valid test

Additionally, in the fall session engagement counts were recorded during each session observation for the duration of the program, for a total of 10 sessions, each lasting approximately 2.5 hours. The spring sessions were video recorded using two cameras positioned in the room to capture movement and audio throughout the space, and observation counts for three of the sessions tallied after the program. The observation protocol was created through research into the design of similar instruments for classroom or afterschool settings (Lane & Harris, 2015; Pearson, 2015). The protocol delineated an understanding of active, on-task behavioral engagement (i.e. raising hand, working on independent task), passive, on-task behavior engagement (i.e. listening to a lecture, looking at a presentation or demo), active, off-task behavioral engagement (i.e., spinning in seat, off-task talking), passive, off-task behavioral engagement (i.e. sleeping at desk, looking out window), active-positive affective engagement (i.e. amazed, joyful, happy), passive-positive affective engagement (i.e. calm, relaxed), active-negative affective engagement (i.e. upset, angry) and passive-negative affective engagement (i.e. sad, drowsy). Counts were recorded at 10-minute intervals (Appendix A).

3.6 Qualitative data

Qualitative data were collected to explore salient elements of the pedagogy and student experience of the classroom environment. Upon completion of the program, four student focus groups interviews were conducted for the fall session and three for the spring session in a quiet room at the students' school, with 3-4 students in each focus group, and including all student participants in the program (n=32). The semi-structured interviews (Appendix B) were audio and video recorded and later transcribed.

During the fall implementation, field notes were taken for each of the ten program sessions between engagement counts–on such details as comments from students and teachers, interactional activity and movement through the room–and used as part of the corpus of qualitative data. It is important to state that observation notes were documented in written form; quotes were copied down with an intention of accuracy and recreated from memory, or general video of classroom, and therefore may have slight alterations to what would be found in a clear word-for-word audio recording. Two researchers recorded field notes for each class in the fall and the observations were made available for checking for alignment and disagreement on the event narrative.

During the spring implementation, multiple sessions were video recorded and one observation was conducted in person. Engagement counts were tallied for three of the sessions and field notes used from the one observed session.

3.7 Data Analysis

In order to test for statistically significant shifts in student engagement and attitude, a paired-sample *t*-test was run using SPSS (IBM SPSS, version 24). Each student received a total score based on an average of all item scores for each construct (*engagement, attitudes toward science, attitudes toward art, attitudes toward nature, and agency*), which was then compared pre- to post-. Distribution was checked visually for normality. Using the observation data, frequencies were run for each activity type's percentage of overall class time, as well as observed engagement types within each activity.

Observation field notes were examined using thematic analysis for "identifying, analyzing and reporting patterns (themes) within data" (Braun & Clarke, 2006, p. 79; see also Glaser & Strauss, 1967). After transcribing observation field notes into a narrative of the class time, initial deductive codes were created based on descriptions in the literature of behavioral engagement and notions of arts-based pedagogy.

To analyze the interviews we used inductive coding under the assumption that language reflects and enables an articulation of meaning and experience (Braun & Clarke, 2006). Because elements of engagement are difficult to observe, such as affective engagement (i.e. *I am happy working in class*), inductive coding was essential to gain a better understanding of student experience. After an initial reading of the first interview transcription, students responses elicited initial codes about their experiences in the program, their feelings about the BioDesign environment, and their attitudes about learning science. This rendered 45 different codes. Across this list, codes were looked at in relationship to each other. This generated six main themes, which after a third read of the interviews, were collapsed into four major themes: *a priori mindset, changing perspectives, responses to pedagogy and experience of physical space*.

The last three focus group interview transcripts were then deductively coded to see if the themes fit, adding or altering a theme if it did not. The observation and interview themes were then compared and aligned to address the overarching research question. Secondary level insights were drawn from the classroom observations with the four themes generated from the interviews. In keeping with the idea that coding is used "to break up and segment the data into simpler, general categories *and* is used to expand and tease out the data, in order to formulate new questions and levels of interpretation" (Coffey & Atkinson, 1996, p. 30), the major themes that emerged from the interviews became deductive codes for the next round of interviews and observations, after a second implementation of the program.

4. Findings

The mixed method design generated both convergent and divergent findings that allow for a more wholistic understanding of if and how the specific curriculum design may have impacted student engagement and attitudes toward science, as well as their experience of the BioDesign classroom.

4.1 Quantitative results

4.1a Fall Curriculum Implementation. Descriptive statistics for the first implementation demonstrated all distributions were roughly normal. Results of *t*-tests showed significantly higher engagement (t=-3.28, p<.01) at posttest (Table 3). Science content scores after the program show a slight increase in mean percentage (2%), although not statistically significant. Review of class activity by engagement counts showed that students spent 58% of their total class time actively working in collaborative groups, independently, or in studio time combining the two (Figure 3). During collaborative and individual work time, students demonstrated a high percentage of positive, active engagement, whereas during lecture and group discussion activities, students demonstrated higher percentages of positive, passive engagement (Figure 4). Negative engagement was rarely seen in the classroom outside of peer sharing and clean up.

Table 3.
Results of t-test and descriptive statistics, FA2018 (n=10)

	Before program		After program		95% CI for Mean Difference				
Outcome	M	SD	M	SD			t	df	*p*-value
Engagement*	3.99	.61	4.39	.47	-.68763	-.12637	-3.281	9	.010
Attitude-science	3.98	.64	4.23	.46	-.63381	.13181	-1.483	9	.172
Attitude-art	3.18	.61	4.14	.78	-.4746	.7546	.515	9	.619
Attitude-nature	4.1	1.10	4.10	1.10	-.7541	.7541	.000	9	1.00
Agency	4.5	.6	4.25	.55	-.15432	.65432	1.399	9	.195
Science content	75.5%	9.87%	77.3%	11.71%	-10.086	6.886	-.427	9	.680

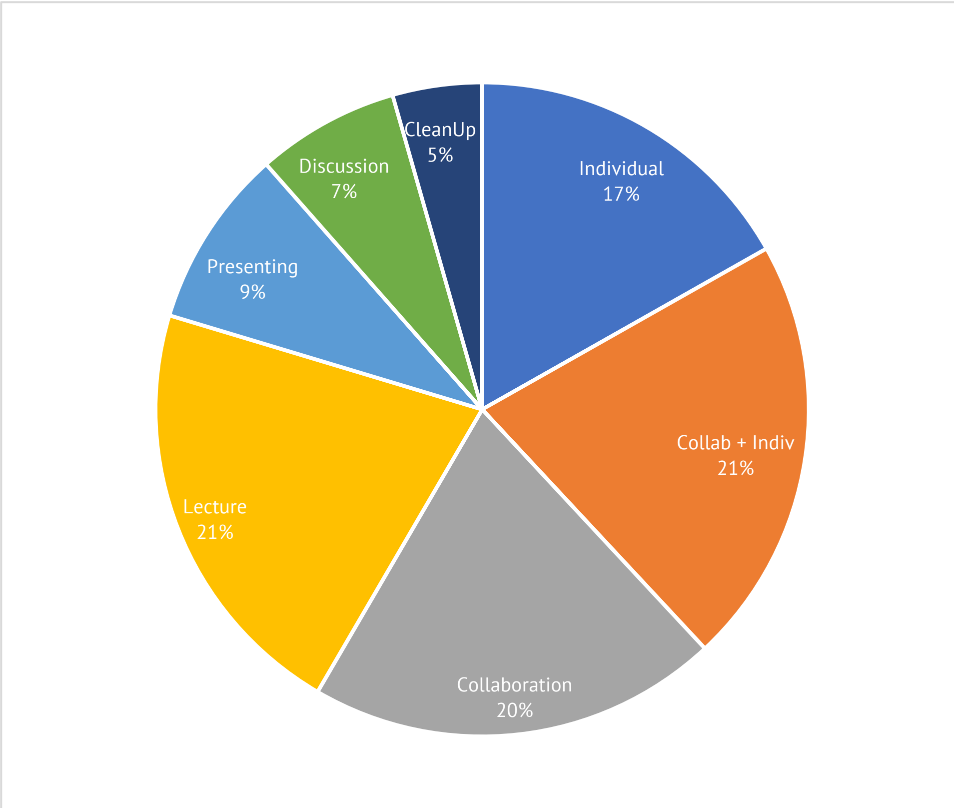


Figure 3. Percentage of total class time hours spent on each activity, FA2018 (*n=10 observations)*

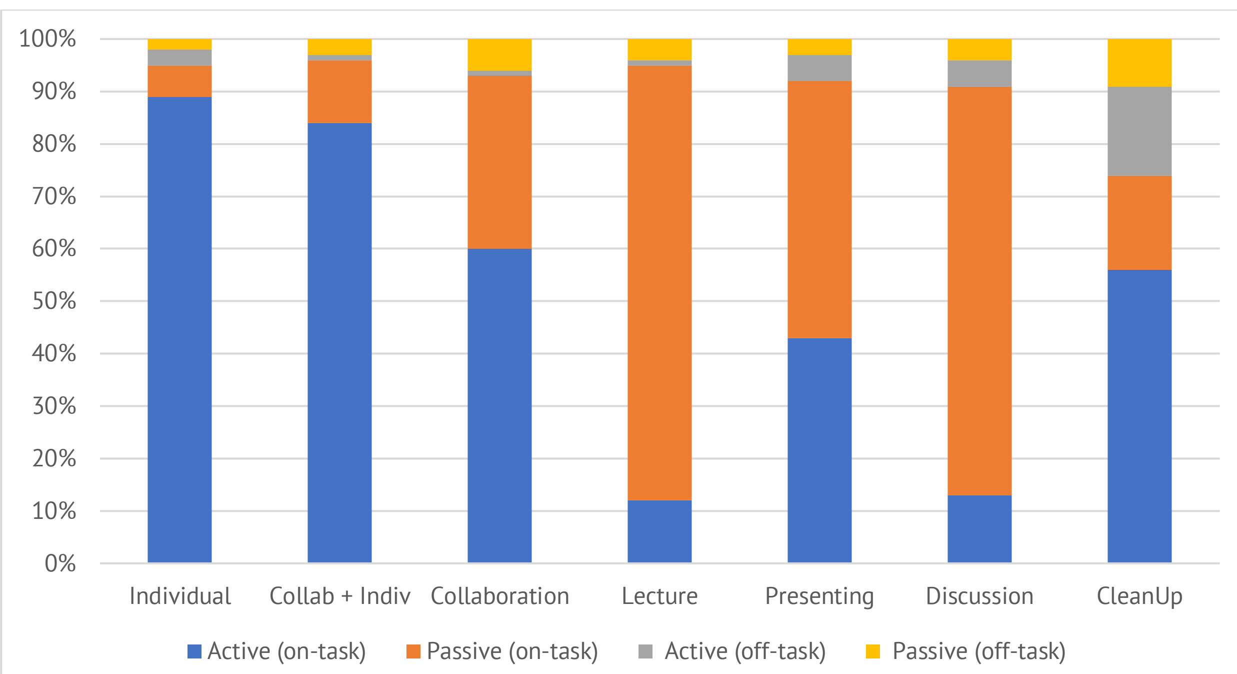


Figure 4. Comparison of engagement type found within each activity, FA2018 (*n=10 observations)*

4.1b Spring Curriculum Implementation. Descriptive statistics for the second implementation demonstrated all distributions were roughly normal. Results of *t*-tests did not reveal statistical significance at posttest for each category (Table 4), yet the mean response for engagement shifted in the positive direction (.53). Science content knowledge scores showed an increase in the mean percentage after the program (4.3%). During the second session, students spent 58% of their total class time actively working in collaborative groups or independently in studio time (Figure 5). During collaborative and individual work time, students demonstrated a high percentage of positive, active engagement (88% or more), whereas during lecture students demonstrated higher percentages of positive, passive engagement (Figure 6). Discussion and demonstrations in the second implementation suggested higher levels of active, on-task behaviors versus prior semester's passive behaviors during such activity times. Off-task behavior, whether passive or active, was rarely seen in the classroom. Overall, the quantitative results suggest that the pedagogy utilized by the teachers has strong potential to engage students in active, on-task learning for a majority of each class period.

Table 4.
Results of t-test and descriptive statistics, SP2019 (n=12)

	Before program		After program		95% CI for Mean Difference				
Outcome	M	SD	M	SD			t	df	*p*-value
Engagement	3.86	.47	4.39	.47	-.18446	.36279	.717	11	.488
Attitude-science	3.69	.63	3.68	.52	-.27700	.40200	.117	11	.909
Attitude-art	3.55	.80	3.88	.76	-.69816	.03149	-2.011	11	.069
Attitude-nature	3.63	.80	3.67	.78	-.51980	.43646	-.192	11	.851
Agency	4.02	.55	3.96	.75	-.27700	.40200	.405	11	.693
Science content	80.80%	11.32%	85.10%	10.44%	-13.317	4.717	-1.079	9	.309

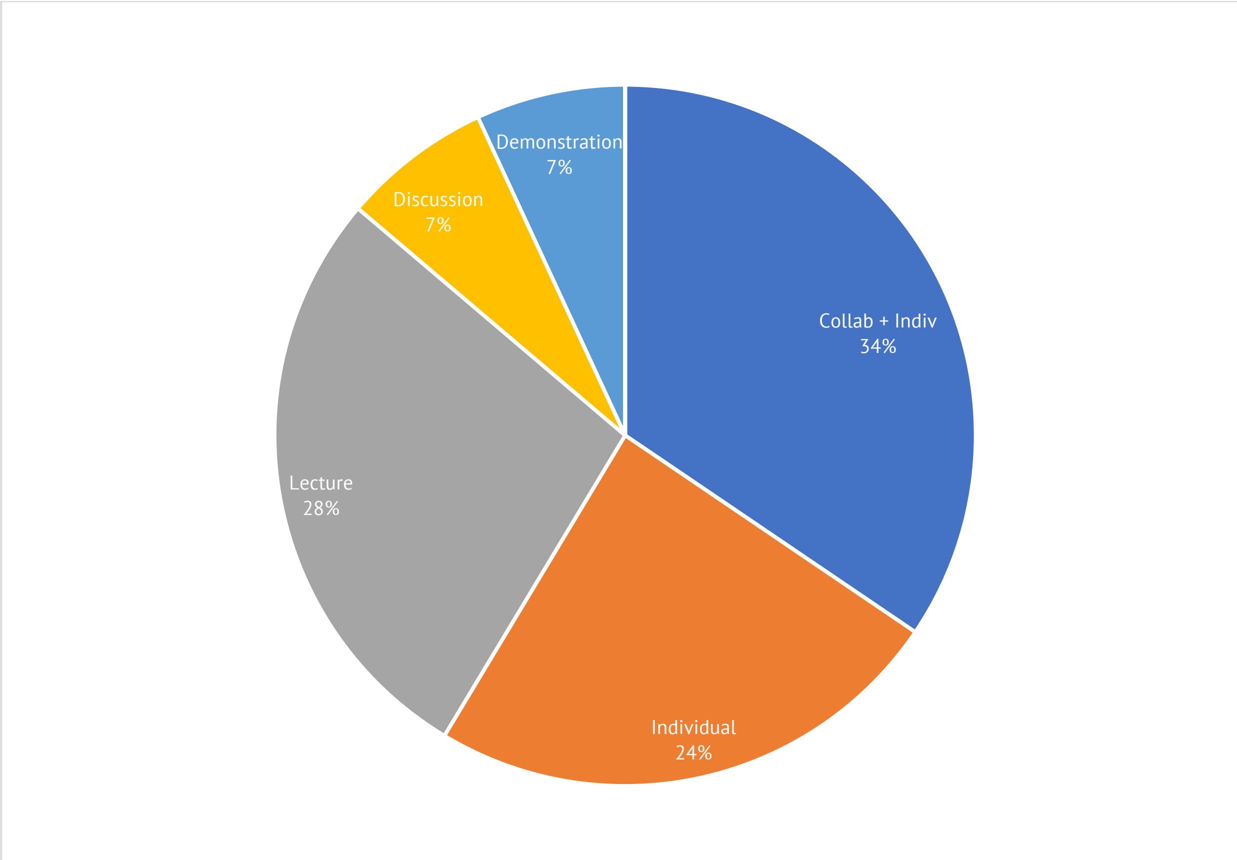


Figure 5. Percentage of total class time hours spent on each activity, SP2019 (*n=3 observations)*

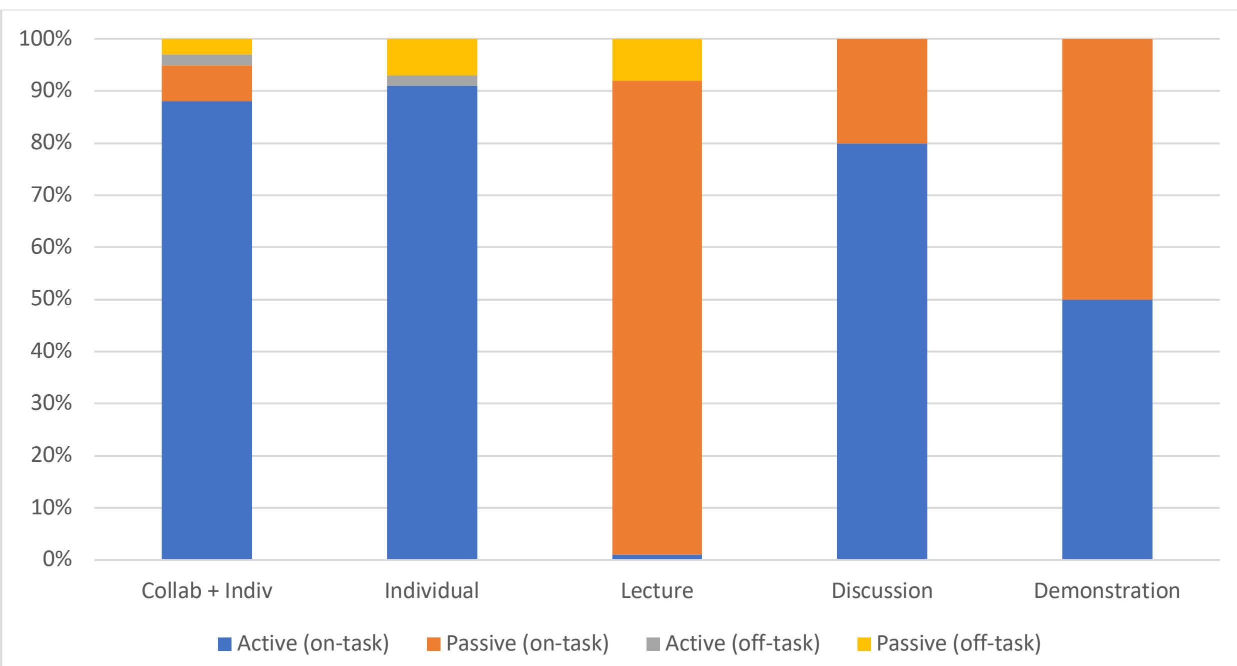


Figure 6. Comparison of engagement type found within each activity, SP2019 (*n=3 observations)*

4.1c Looking across both program sessions. Descriptive statistics that considered all students who participated in the program for which we had complete survey data (*n*=22), demonstrated increased means in engagement, attitudes toward science, and attitudes toward art. Post-test scores for science content also indicated an overall increase in the mean percentage (2.95%). Although not reaching statistical significance within the ten weeks of each program session, the shifts in response are worth noting when interpreted alongside qualitative data.

Table 4.
Results of t-test and descriptive statistics, Program totals (n=22)

	Before program		After program		95% CI for Mean Difference				
Outcome	M	SD	M	SD			t	df	*p*-value
Engagement	3.92	.53	4.06	.60	-.34763	.07490	-1.342	21	.194
Attitude-science	3.82	.64	3.93	.56	-.31567	.10203	-1.064	21	.300
Attitude-art	3.84	.77	3.95	.75	-.44618	.20982	-.749	21	.462
Attitude-nature	3.84	.96	3.86	.94	-.41261	.36716	-.121	21	.905
Agency	4.24	.61	4.09	.67	-.09333	.38878	1.274	21	.216
Science content	78.25%	10.66%	81.20%	11.52%	-8.563%	2.663%	-1.100	19	.285

4.2 Qualitative results

Using deductive codes for the observations based on engagement types, and inductive coding from the focus group interviews, offered results that we could integrate to widen our understanding of student experience in the program as it related to the main elements of our research question: student engagement in and attitudes toward science learning, art and design teaching pedagogy, and experience of the BioDesign space (Table 5).

Table 3.
Alignment of Focus Group Interview and Observation Themes

	Interview Themes	Observation Insights
Engagement with science content	• a priori mindset • changing perspectives	• students struggle to retain specific science content • students are highly engaged in working with their hands
Pedagogical approach	• a priori mindset • changing perspectives • responses to pedagogy	• art and design pedagogy reified • traditional science pedagogy reified • traditional science pedagogy (cautiously) transcended • epistemological focus of arts foregrounded • students highly engaged in working with their hands
Biodesign environment	• experience of space • interest in specimen collection and aquaria	• positive affective dimension to space • space was underutilized in implementation 1 but became more central in implementation 2

4.2a Engagement with and attitudes toward science content. Interviews and classroom observations offered complementary views on the perspectives students had about science learning going into the program, and how that changed over time. Data for this understanding came from the interview themes of *a priori mindset* and *changing perspectives*. In understanding shifts in thinking about art or science, we can better ascertain if the program had the potential to engage students in new ways of thinking and doing with science.

As students talked about prior science class experiences, consensus formed about what that experience was like. One student stated, “At my old school…. you sit in one class and have a notebook and just take notes (Group 2 interview, 12.10.18).” Another reinforced this notion saying, “Every day we sit down and take notes and just listen to every single instruction the teacher gave of information and write it down (Group 2 interview, 12.10.18).” These comments reinforce ideas about traditional science pedagogy, wherein the teacher lectures and the students passively listen.

Students also came into the program with strong disinterest in science. One student exclaimed, “I failed science in middle school and I dislike science so much (Group 1 interview, 12.10.18)!" which was greeted by a mutual, emphatic head nod by all but one student who mentioned he was interested in computer science. In the second interview group, one student stated,

> To be honest I really didn't like science at all. I hated science when I was in elementary and middle school because my science teachers they were all boring. And …they made science boring (Group 2 interview, 12.10.18)

This was reinforced by another student who said, "I didn't really like science. That was my least favorite topic." This is expanded upon by a student who articulated:

> Science confuses me, but it's not that it's a lot, but it's that I can never understand how they figured it out, and it feels a lot like: "Oh, this is like this because it is," and I don't like that. It confuses me (Group 3 interview, 5.7.19).

This stands in notable contrast to students who stated in their interviews, "I like art" or "I like to draw" or "I was interested in art." Not one of the students mentioned a negative association with art or past art classes. In general, students mentioned a limited understanding of what art as a broad discipline entailed. One student commented, "In regular art classes you're just like assigned something to do and then you have to do it perfectly with shades…Art class is mainly about drawing (Group 2 interview, 5.7.19)." Students perception of what art making centered on drawing and realistic rendering.

When asked about their experience of science after participating in the program, students' comments addressed how their perspectives shifted. One student commented on a shift in his thinking, originally having thought it was going to be like a traditional science class, he noted, "I also didn't like science at all. It wasn't really that interesting to me, but with [the program] it kind of like made me open-minded about science, and I really enjoyed it (Group 3 interview, 12.10.18)." Another student stated, "I know we learned a lot about science, but it didn't even feel like science. It was like…to me going was fun, so I don't really think of it as science (Group 1 interview, 12.10.18)." One student's comment went further to state, "I felt like this [class] was more to do with actual things that we could potentially use rather than like – there are two hydrogen and one oxygen and that is water (Group 3 interview, 5.7.19)." Such comments point to both students' prior beliefs about science as well as their level of engagement with science content as it was presented in this program. One student put it, "It changed the aspect of science to me because I know that science can be more engaging…It could get your mind thinking and not be lazy about it and be artistic and creative with it (Group 2 interview, 12.10.18)." While some students interviewed were unsure of any change in their ideas about science or scientists, no comments suggested a negative shift in affect around science learning. One student even advocated for bringing such a program into schools saying:

> I feel like if this program was to happen in schools it will benefit the children because…they will be more interested in science and they'll be all, "Oh yeah science is actually really fun" …. It could probably change their perspective on science like how it did to me (Group 2 interview, 12.10.18).

By advocating for the program, the student here indicates her own shift from prior experience and definitions of science learning to an expansive understanding of what science learning could be.

Evidence of students' cognitive engagement emerged through stories of bridging in-class learning to their outside-of-school lives, and their growth in personal agency. After their participation in the program, students discussed shifts in their sense of what they could do about big environmental issues. One student stated,

> When you look at how there are so many people around you, you're like, you're one person. You don't feel like you could do much, especially as a teenager. But when you do things like [the program], with people, you're like 'I can make a difference in this world'…. I feel that did open my eyes (Group 1 interview, 12.10.18).

For this student, learning about issues with a group of people added to a sense of possibility to make a difference. This was reinforced by another student whose sense of agency was invigorated as she noted, "Before the program I was thinking I'm like one person out of the world, how am I going to help…but it made me think I probably can't like change it but I can help push to make change (Group 1 interview, 5.7.19)." Both students articulated feeling overwhelmed by the grand nature of the environmental issues but also empowered through the program to make a difference on an individual level.

Many students focused on the topic of recycling and waste as the area in which they could make an individual impact, a topic brought up in multiple ways over the course of the program. One student remarked, "I remember like I used to litter…like "Oh who cares, it's going to go away." But now… I literally wait and hold my trash until I walk past a trash can (Group 2 interview, 12.10.18)." Another student stated:

> It made me think a lot more about the world that we live in today because right now, the Earth is suffering…after that [program] I've been a lot more interested in seeing what we can do to help the earth heal again, and there's only a certain amount of time before everything that we do is irreversible. (Group 1 interviews, 5.7.19)

This suggests a cognitive engagement with the material in that the students had taken the information discussed in the class and brought it beyond the walls of the classroom, changing behaviors and continuing to think about the content they had been learning.

Observations. Whatever the *a priori mindset* of the students, they came into class with an open attitude, ready to learn. For example, given their task to prototype a solution to a single-stream plastic use problem, they were interested in how some materials had low melting points or were impermeable to water and were motivated to find the right material for their individual designs. Below is a reflection from a classroom observation:

> [The biologist] encouraged students to lift up the skin-like culture that had formed in each tray and handle it, and they leaned in as she showed them how to carefully harvest it (as students said things like, “uhhhh, gross”). Students then transitioned to the tables in groups of 3-4 to find their dishes of kombucha. A few exclamations could be heard from the students such as:
>
> > “It smells like apple cider!”
> >
> > And, “Is mine supposed to be thicker? Mine is really thin.”
>
> (observation, Nov.1, 2018)

However unusual or out-of-the-box the experience provided was, students seemed to put aside their expectations and fully participate. This reinforced description of favorite science experiences as being hands on and full of experiments, such as the student who said, “[The program], it’s not just like science where you’re putting your head down falling asleep. It’s like something you’re engaged in (Group 2, 5.7.19).” This was also observed multiple times in students’ excitement to share what they were working on with their teachers and peers.

It was a rare occasion to see a student actively off-task in their behavior. On one such moment, a student took her small works-like prototype and squashed it out of frustration (observation, 3.7.19). After multiple attempts to make a flexible structure, and support from the teachers in the room, this student's difficulty manipulating the paper had finally surfaced. The challenge presented by these seemingly simple tasks could be seen as stages in some of the students design process, articulated by one student saying:

> Even when you try to give up and I'm just like over it, they push you and I like that because like the past science that I did go to, most of the time they didn't really care. They just continued with it. They didn't realize – "Oh, I need to push her to do it" (Group 2 interview, 5.7.19).

Acknowledging the difficulty, she had coming up with ideas and becoming proficient in a technical making skill, this student identified the behavior observed and the importance of being pushed through to multiple iterations. This adds an element of teacher-student interaction to the level of active, on-task engagement students have in the class.

Passive, on-task behavior was most apparent during lecture, video, and demo structures within the class, seen in attentive listening with eyes focused on the projector screen, responses offered to question prompts, and spontaneous remarks made about what they were seeing. When students moved freely throughout the room, their affect ranged from active, on-task, seen in happy banter and enthusiasm about developing their work, to passive, on-task, such as being absorbed into their project prototyping, comfortable and at ease. They showed pride in and a commitment to what they were making, seen in exclamations of "Can I show you…," and in discussion with their peers, taking time to talk through their idea and searching for support for better functional mechanisms, such as a way to clasp a reusable lunchbox, a better hinge for a box lid, or a working model after multiple iterations (observation notes, Nov.1, 2018, observation notes Mar. 7, 2019).

It also became apparent that students had a hard time recalling specific science information. When the student teachers and biologist asked refresher questions such as, “What is a polymer?” or “What does it mean to biodegrade?” students were hesitant to answer (observation, Nov.1, 2018). Although they each had a sketchbook meant for notes in class and writing down ideas, few referenced these notebooks for an answer, or seemed to be taking notes in it during the lecture portion of the class, suggesting that it was either not in their notebooks or they didn’t realize they could go back and look for the information. This seemed to be true despite efforts in the second implementation to formally reinforce the vocabulary being taught each class session through games and notecards. This suggests that students, despite demonstrating high levels of engagement, were not necessarily internalizing the specific science understandings such as polymer formation. Another example was seen during the interviews in which students struggled with words such as “biomimicry” and “biodegradable,” not having the recall of the terms a few weeks after the program ended.

When working toward an understanding of students’ behavioral, affective and cognitive engagement in the classroom, prior experiences, expectations, definitions and interest with a subject can act as limiters or deterrents before a class even begins. Here the students’ interview responses and classroom observations revealed an engaged class, surprised and delighted to be doing hands-on work in a science classroom and invested in the content enough to impact behaviors outside the class time. Observations corroborate this and add a cautionary insight that this may be at the cost of content specific language necessary to make the program successfully transdisciplinary, where learning goals for both subjects are met.

4.2b Pedagogical approach. Another theme generated from the interviews centered on students response to pedagogical choices made by the teachers. The pre-service teachers, with expertise in studio pedagogy, designed the curriculum in coordination with the scientist collaborator. A key element of this study was to understand the effects of this pedagogy on student engagement.

Interviews. One student commented, "[The program] is different because…they made it more fun for me, more engaging and more interesting (Group 2 interview, 12.10.18)." Although a very general statement, it suggests this students' level of engagement with the class was in response to the way teachers presented the content and activities. Another student adds clarity saying:

> It was different because we got to do our own thing and … make prototypes of things that we created. Like I made this little parachute and I made a prototype of that and it was pretty weird but it was still cool at the same time. And it's kinda based off a jellyfish. So, it could work on like in the air and under water (Group 2 interview, 12.10.18).

Similar to a typical art class, students were encouraged to connect their *personal interests* to the assigned project. One student noted that what made the biomimicry unit interesting was "I guess I could choose whatever I wanted, and I drew it (Group 1 interview, 5.7.19)." This capacity to choose the direction of research or the final artifact of output is often not an aspect of non-arts classes, and stood out to multiple students.

Several students specifically named the *hands-on* aspect of the program through the opportunity to actively engage with the content beyond a lecture. The lecture format, seen as the traditional method of content delivery in science class, was mentioned again later by a student who said, "I'm more a hands-on person. I'll listen to you for like 10 minutes. If you go over 10 minutes, I kind of like zone in and out (Group 1 interview, 12.10.19).” This was quickly picked up by a peer who said, “I'll give you five!” Another student remarked, “Like with the bioplastic…it doesn’t really make sense when they tell you about it, but when you like make it and then you can like hold it, it makes sense (Group 3 interview, 5.7.19).” One of the strengths of this program was the capacity to bring the science content to life through the hands-on manipulation of materials, as well as the opportunity for students to pursue personally motivated topics.

Multiple students mentioned the *collaborative* nature of the program. Through in-progress and end of project critiques, students discussed challenges and questions they had in the process of building their skills and knowledge. One student mentioned:

> I really liked the conversations me and [the teacher] would have. Like I feel like she really got to understand me, like all the things that I would say; I feel like I got to make my points of view heard…And all the other students and my classmates were actually also there listening and actually collaborating to what I was saying. And I feel like that's something that I really really enjoyed about the class (Group 4 interview, 12.10.18).

A critical part of arts pedagogy is the collaborative feedback sessions in which multiple perspectives are elicited and valued as the work develops in class. Community members have a chance to hear their peers’ thoughts as well as offer their own while they learn and work alongside each other.

In trying to understand the pedagogy in use, it is helpful to look at where it allows for *freedom from disciplinary silos*, and if there is an epistemological hierarchy formed between disciplines. One of the goals of the curriculum design was to foster an inquiry that did not privilege art and design or science. When asked about how the two were experienced together by the students, one responded:

> I definitely feel like it was really brought together … in a really cool way. They didn't only focus on the science but also about the art aspect…. When we drew our specimen and …created something out of it was something really cool to me …and the little tank…I feel like it definitely combined both science and art and that's what made it as interesting …as it was (Group 1 interview, 12.10.18).

Here the student identifies two projects: the design of an artifact based on a specimen from the natural history collection, and the creation of a compost tank as part of a lesson on biodegradable materials. Both of these activities incorporated science and art content. The biomimetic design project was also mentioned by another student as, "you kind of have to use art to make a prototype and then it's kind of mixed in with a lot of different things like math and technology and stuff (Group 2 interview, 12.10.18)." The two projects stand out to the students as moments where the art and science came together seamlessly to achieve the outcomes of the activity. In both projects, students grappled with science content such as evolution, changes in environment and the cycling of energy in nature. Additionally, they had their hands in and on the content being discussed.

Another concept that emerged from how the art and science were being taught together was grounded in the *content or inspiration* driving the art. One student, in noting that the program equally developed the art and science, said, "Behind the art it's always like a story. And like a subject that we're learning so it comes together in a way to make one big story (Group 2 interview, 5.7.19)." Another stated, "it's like really even, but maybe a little more science because the ideas I guess were like science and then you would make it (Group 3 interview, 5.7.19)."

Students identified that the ideas behind the work they were creating were grounded in the disciplinary content of science.

Students did express some dissonance in categorizing the content as nature-focused, and coming to terms with whether or not that also meant science-focused. In trying to decide if the course felt more like an art or a science course, one student responded, “It was mostly like nature (Group 1 interview, 5.7.19).” Another student linked the two saying, “Nature and science are pretty much hand-in-hand because nature is a part of science (Group 1 interview, 5.7.19).” This presents an interesting area of discussion with students who are trying to understand where the boundaries of disciplines reside and how to categorize content.

Observations. In an art studio classroom, students are encouraged to explore materials through their hands, by starting with an idea, addressing the idea through a given art medium, and then reflecting on the success of their artifact to later iterate on the design (Marshall & D’Adamo, 2011). There is not one, but rather many, right answers. We saw this in the classroom observations where students had freedom to push their individual ideas and material exploration as they needed; students had the opportunity to explore the concept versus complete a linear lab. The majority of the time was devoted to making and prototyping, with student teachers rotating throughout the room offering design suggestions and support (Figure 5). Students were encouraged to try out multiple design ideas, to brainstorm and prototype with multiple solutions posed at each table using supplies spread throughout the classroom, such as wooden dowels, pre-made mycelium bricks, rolls of bioplastic, and tools to cut, melt, adhere and manipulate the supplies.

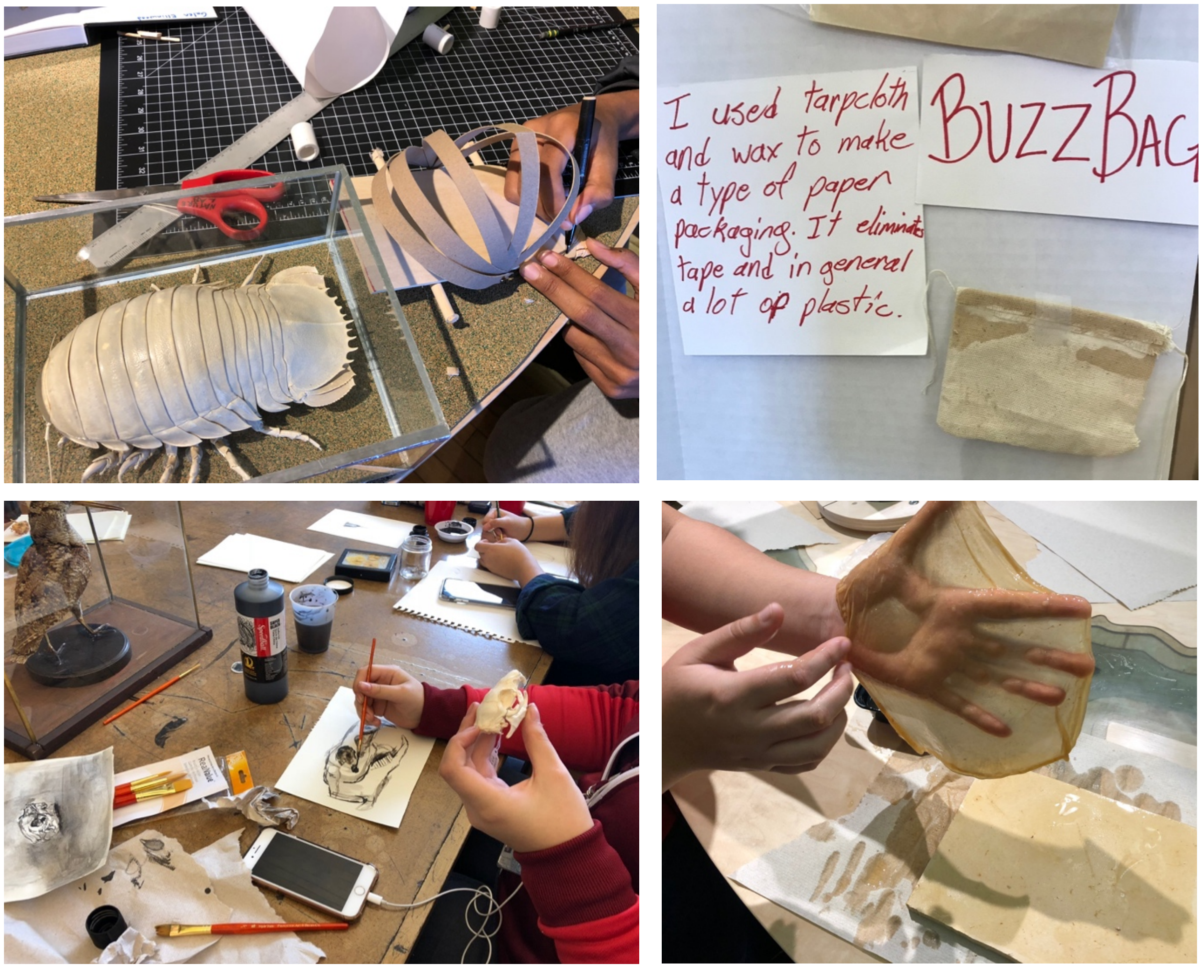


Figure 7. Images of students engaged in maker activities in the Nature Lab.

The way that the co-educators set up the class demonstrated that they were highly engaged with the students and valued student voice. Efforts to record and document what the students said were seen in the charted papers saved from the prior week. Rather than one student coming up with one design solution per table, the student teachers encouraged multiple ideas with enthusiasm such as “yes, write that down, write that down!” At another table a teacher saying “tell me more” suggested genuine interest in what the student was saying and a desire to help the student to fully communicate and think through their idea. Also, statements of excitement were heard such as when one student talked about applying on biomaterial (wax) to another (yarn) to make the second one waterproof, to which the student teacher grew very excited and said, “Yes! Right! That’s great!” (observation, Nov.1, 2018).

Conversely, the types of initiation-response-evaluation questions students were asked happened primarily during the lecture, which could be seen as anchored in traditional science teaching practice. For example, throughout the program, review of scientific concepts, such as “What is a polymer?” happened quickly at the beginning of a class, a question with one right answer. Students answers were either given a yes or no evaluative response. In another class, the question posed was “What do you think I mean when I say *BIO-materials*?” After students guessed at the answer, the teacher went on to offer the right answer. Questions such as “How does nature do design?” elicited more guessing from the students, yet it became clear the educator was still looking for one answer, “evolution,” despite open-ended potential of making this a compelling question which was answered through student investigations. This type of question-answer sequence highlights the challenges of transcending traditional science pedagogy in an effort to ensure science content is taught, and the inclination to fall back on traditional practices when relaying important vocabulary and concepts to students.

4.2c The BioDesign Environment. A final area that was a critical part of the program design was the physical space of the classroom. Often an afterthought to the pedagogy of a classroom, in this program it was central to the conception.

Interviews. During the interviews, students mentioned predominately positive ways in which the physical environment impacted their experience. They mentioned the classroom as drawing them in through being startlingly different than any classroom they had been in before. One student stated:

> For me the thing that I really like about the classroom is that it doesn't look like a classroom. It doesn't look like you have your little desk and your little chairs…. You have different things like the green wall the fishes, like the little tank that have the animals and you have different things to bring your mind into and explore…. I just really liked it and it didn't feel like…. in a box. Like you felt free to do your own thing, or free to explore your own mind (Group 1 interview, 12.10.18).

This difference was reinforced by multiple students who commented on it being unlike anything they had experienced, especially the living green wall and the fish aquaria. Another student framed it:

> I really liked it. It was something different. I walked in and I was like 'hmmm'. But then I saw all the different types of fishes and the seahorse and I was like "This is so cool!" And I liked the plant thing behind it (Group 1 interview, 12.10.18).

Students recognized the impact of walking into the space while realizing "…we're about to learn all these things (Group 3 interview, 5.7.19)." Upon first glance, they were already stimulated by the environment and its potential for their learning.

The students' demonstrated a positive reaction and affinity for the space. They consistently used the words, "calming", "relaxing", "peaceful", and "soothing" to describe the space. They agreed with each other's descriptors of "beautiful" and "cool." One student described it, "when I walked in I had this feeling like cool water, and just being like chilled and…this is a safe place to be, and I can just relax (Group 2 interview, 5.7.19)." A few students brought up the inspirational aspect of the space as well, offering "It made our minds for just one to wander around and bump into ideas (Group 2 interview, 12.10.18)," and "it looked so futuristic or something, so it just gets more people's interests more (Group 2 interview, 5.7.19)."

Figure 8. Biodesign learning environment at the *Nature Lab*

Only a couple students articulated negative experiences. One student said, “It was kind of weird…because there was so much that was in the room (Group 1 interview, 12.10.18).” With two aquaria, an aquaponics feature, a green wall, multiple organic shaped tables that rotated around two supporting columns in the space, a large mycelium armchair, and other tables with lab equipment, the students also picked up the sheer number of elements competing for attention in the space, which was also operating as a showroom (Figure 8). One student stated, “I had to sit away from all that stuff cuz like I would have been distracted in classes (Group 1 interview, 12.10.18).” While each feature in the room was designed to be modular and able to be built and incorporated into a classroom on its own, as a repository for all of the Phase One design ideas, the classroom was also perceived as crowded and potentially distracting. Another factor was the newness of the environment. One student commented, “I’m not really a fan of animals so seeing all those animals was like a really weird feeling. But I got used to it (Group 2 interview, 5.7.19).”

It was clear that the Biodesign classroom was a new experience for them, one that they felt impacted their behavior in the space. In comparing it to a traditional classroom, one student said:

> I feel like traditional classrooms are boring. So you find things to do like with your peers or something. But with that class, you can look at something without talking to your friend while still paying attention (Group 3 interview, 5.7.19).

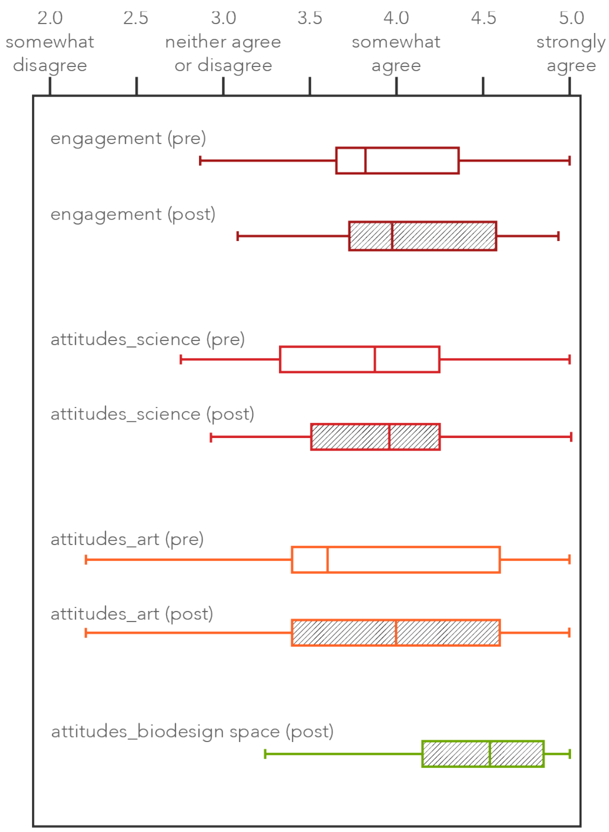
Students noticed the environment in which their learning was situated as a vibrant, stimulating context. Yet it did not hold them back from the ultimate purpose of the space, describing it as "relaxing, but it still felt like a place to learn (Group 3 interview, 5.7.19)."

Finally, students also recognized that certain elements of the room lent themselves to the curriculum being taught. One student specifically mentioned the aquaponics feature in the room stating, "In one class they were explaining to us about how organic stuff was created in kitchens, and they used the fish to like use …. the bacteria for the soil. And there was one in the back so we got to see one (Group 1 interview, 12.10.18)." This came up more in the interviews after the second session, such as by a student saying, "the environment was just like the lessons that they taught (Group 2 interview, 5.7.19)." Another student mentioned, "the fish and stuff gave me an idea for what to do…I had to watch how the fish moved exactly. That's cool…the watching and getting to figure it out (Group 1 interview, 5.7.19)." These moments stuck out to students as a seamless movement of the content into the lived experience of the space, summed up by one student who said, "it makes it more concrete since it's kind of all around you (Group 3 interview, 5.7.19)."

Observations. This last point brings up the potential of the BioDesign space. During the observations of the first program implementation, I had noted that throughout the class, the students and teachers seemed to exist separate from the physicality of learning space in which they were. Despite it being filled with biomaterials such as cork matts on the tabletops, enormous aquaria filled with little sculptures, a living wall the size of one side of the room, the teachers rarely pointed out any of these elements in the room. During multiple observations, a staff member of the lab continued to move around in the background to clean out the tanks, dust shelves, and feed fish as separate activities from what was being taught. In the first semester, observations suggesting the space was not utilized as a “third teacher” despite it being a critical part of the intervention program. Observations of classes during the second implementation of the program demonstrated that an effort was made to bring the physical environment more into the forefront. This was done primarily through individual drawing exercises (observation, 1.25.19) and referencing different BioDesign modules in the room as students were working (observation 3.7.19).

4.3 Looking across methods

4.3a Confirmatory. Taken together, the quantitative and qualitative data for both implementations align to suggest that the Biodesign curriculum was engaging for students and had an impact on shifting their attitudes toward what constituted science learning and art making. (Figure 9). Despite not finding statistically significant results, students responses to interview questions aligned with positive shifts found in mean responses to survey items around engagement, attitude toward science, and attitude toward art. Student descriptions of the space in the interviews coincided with responses in which they “somewhat agreed” or “strongly agreed” with positive descriptions of the room and interaction with nature, as described through the structures of the room as well as the content and material of study. They spoke about the ways the space inspired them in their design work and the affective dimension of the learning environment.



Students sat at four tables in small groups of 3-4. Their hands were busy manipulating paper to demonstrate different types of movement that they had seen in their chosen specimens. They worked independently, or approached an available teacher or teaching assistant, to ask questions about techniques or the specimen's functions. They were eager to show what they working on to the teachers and their peers as they made small improvements and iterations in the flexible forms. One student asked, "Miss, can I work on this after school?" (observation notes, 3.7.19)

"Your mind is way more engaged than just like a normal class where everyone is like, "oooh, science (emphasis and an eye roll)". When it comes to science and art, you want to go do it"

"It just makes science interesting because like you don't want to go in a room and sit and read a book, like a textbook.."

"I think you also retain a lot more information. Because like with a lot of science classes I know the general stuff, bit I don't like retain much of the information. But with this, I...know what I did; I know why it happens an all that...I remember it."

"I learned that besides making stuff look good, they have a purpose behind it, like making the world better and stuff." (Group 1 interview, 12.10.18)

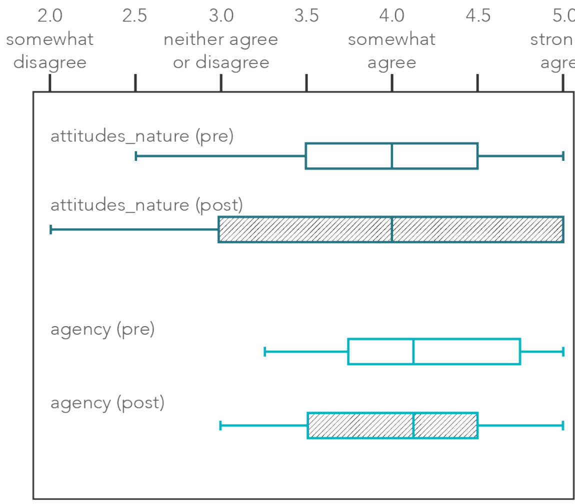
"In [the program] you were doing a lot of...like thinking big. It was thinking bigger, like more than just a pen and a paper." (Group 3 interview, 12.10.18)

"In the last lesson, which was aquaponics, they showed us an example because they already had a system [in the space]. So we were able to understand, and see for ourselves." (Group 1 interview, 5.7.19)

"I feel like the space that we were in, it kind of made it easier to learn because what they were talking about--like using the water from plants and recycling the water from plants and putting it into a fish tank--like they had that there so we could see it, and I feel like all the plants and stuff around us, it really inspired us to make different projects." (Group 3 interview, 12.10.18)

Figure 9. Confirmatory findings across quantitative and qualitative data.

4.3b Contradictory. While paired samples t-tests suggest no significant shifts in student's attitudes toward nature or sense of personal agency from the beginning to the end of the program, group interviews with students indicated that students did in fact internalize aspects of the life science content being discussed, as well as changes in behavior grounded in what they had studied in the program (Figure 10). Many students focused on a shift in their relationship to environmental awareness and the use of non-degradable plastics, a focus of the biomaterials unit in the program. They talked about design inspiration from nature as well as the need to protect biodiversity for continued exemplars of how nature operates with limited resources in ways that are not harmful to their environment. In conversation, students were clear that this program had an impact on their lives outside of the school environment.



"So I think 'Oh! Look at all these animals that are going extinct!' and then I think of art pieces or technology or anything at all that we have today that could have been inspired from that and I'm like, 'If this animal [did] not exist we might not have what we do today. And that's basically what we're going to end up doing."(Group 4 interview, 12.10.18)

"I learned a lot about Earth's ecosystems and animals' ecosystems. So I'm incorporating that into my life by using all of the information I learned in [the program] and how I, as one, can try to make an impact to make our world more healthier and more cleaner, for not only ourselves but the animals that are around. And I'm passing that on to the people I live with, my family and my friends." (Group 3 interview, 12.10.18)

"I feel like before the program, I was thinking like, 'I'm one person out of the world. How am I going to help the world?' But I guess it made me think like I probably can't change it but I can help push to make a change." (Group 3 interview, 5.7.19)

Figure 10. Confirmatory findings across quantitative and qualitative data.

5. Limitations

An efficacy study such as this includes many limitations that prevent scalability as a quasi-experimental or experimental design might, limitations that are worth acknowledging. First, the project had a small sample size without the power to reliably determine effect for strong statistical findings. Second, students were enrolled in a non-traditional school, which might suggest increased levels of parent involvement or student advocacy, making this convenience sample more prone to high engagement levels. Third, despite efforts to control variables, each session contained different groups of students who presented a different dynamic, as well as a different configuration of teachers. Fourth, funding necessary to create specific BioDesign features can be costly, limiting who may be able to construct such designs within their own classroom space. And finally, living systems need continued care and attention which might be problematic in many public school environments.

6. Conclusion

This study sought to investigate the question, "*How does a nature-rich life-science curriculum, taught through an art and design pedagogy in a newly built BioDesign makerspace, appear to impact student engagement in and attitudes toward science content?*" Teaching science content through an art and design pedagogy in a makerspace environment describes an inquiry process, a social context, and a facilitation method grounded in a constructivist paradigm which centers personal meaning making and hands-on learning. The results of the study suggest that the curriculum design, pedagogical choices and affective affordances of the BioDesign space offer a promising way to engage high school students in life science content with an engineering design component.

In keeping with literature on studio pedagogy, students felt part of a community of learners, and that their ideas were of value. They responded positively to the use of student choice and personal interest, hands-on activities, and the undercurrent of relevant and meaningful content. Activities that shifted between individual and group work time kept students actively engaged and curious about content delivered in the lecture format. By combining demonstrations, experiments and making, teachers effectively engaged students in the curriculum being taught.

Students expressed their unquestioningly negative prior beliefs about science learning coming into the program, and most demonstrated little interest in pursuing science or science careers, confirming what was found in the literature. This is reinforced by research that suggests most students form their science identities between middle and early high school years (Calabrese Barton & Tan, 2018; Saw et al., 2018). The program offered an opportunity for students to shift their attitudes toward science, perhaps opening a closed pathway to STEM disciplines. Many left thinking about science existing beyond a man in a white coat working in a lab, to encompass the living context around them, which they began to understand as including nature. One student had not considered that she would need science to become a veterinarian, changing both her preconceptions and her enthusiasm to pursue science in the course of study to reach her goal.

The conscientiously created space emerged as an important aspect of the curriculum. The environment in which students learn, which often simply forms the backdrop for learning, has the potential in the BioDesign space to draw students into the wonder and curiosity integral to the science discipline, acting as a third teacher. With the second iteration of the program, strong attempts were made to root the curriculum more securely in the space through observational activities as well as utilization for examples of content being discussed.

In returning to the literature on *biophilia*, this study adds to the notion that humans are inextricably drawn to nature, and that it can have immediate positive cognitive, emotional and behavioral effects on peoples' health. Students were both affectively and cognitively engaged by the living organisms in the space, from the fish in the aquaria to the diffused ceiling light installation. They described its soothing, calming and relaxing qualities, emphasizing that it felt meditative. Based on their interviews, students found the room stimulating and energizing, making them feel both calm and awake, adding to their learning and their inspiration. In stark contrast to rooms that are flooded with fluorescent lights, sharp geometric forms and often have no natural features or windows, students identified the allure of the space and appreciation of doing the program within the space.

If we are truly committed to fostering engagement in STEM learning, we will have to suspend rigid notions of what a classroom looks and feels like. Wavering in terms of where to place the program on a scale of "science" to "art," students discussed the way the teachers in the program were able to move fluidly through both disciplines, offering support for the concrete vocabulary and bridging the learning to their world outside the classroom. Collaborations that are transdisciplinary in nature may require disciplinary co-teaching teams who plan and teach content together, drawing out the overlaps and connections for students, as the art and science teachers did in this study.

This study also highlights the need for continued research. Longitudinal data collection and analysis is critical for how such a program might shape students' thinking and disciplinary identity into the future. The novelty of the program and the space was clearly articulated in student interviews, and it would be important to see how continued exposure might enhance or dull the findings. A follow up study could focus on constructing BioDesign spaces and implementing the curriculum with art and science teachers from public schools in different settings for increased sample sizes and comparisons in broader learning environments. Additionally, such curriculum can be strengthened by teachers required to prepare students for science testing and meeting NGSS or other standards requirements.

The study suggests transformative potential in reframing what form research and knowledge can take, opening up pluralistic response youth may have to science content. Empirical work in the study of biophilia, especially with youth, is minimal and results inconclusive. Controlled experimental designs take place in labs, removed from the real-life environments in which students live and learn. Mixed-method studies such as this one offer multiple ways of accessing what the experiences are in such environments, and where efforts can be made to expand traditional teaching practices to better engage young people in exciting STEM worlds.

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Appendix A: Observation Protocol

NATURE LAB BIODESIGN OBSERVATION PROTOCOL

Date:

Program:

Class # in Sequence ___ /10

Location:

Resources in use:

# of Students

Instructor(s):

Observer:

Start time:

End Time:

Key for Behavioral and Affective Engagement Counts

	BEHAVIORAL	AFFECTIVE
ACTIVE +	Student is actively attending to given task: raising hand, talking to instructor about material, giving feedback during critique, manipulating physical materials for assignment, sketching ideas for project, talking to peer about project, using computer for notetaking or on-task research, reading aloud; nodding in agreement, leaning forward; making verbal observations, asking or answering questions	Signs of following emotions (>3s): amazed, joyful, happy, enthusiastic, eager, inspired
PASSIVE +	Student is passively attending to given task: listening to a lecture, looking at handout, listening during critique with eyes focused on work being discussed, reading assignment sheet, researching on computer, listening to peer	Signs of following emotions (>3s): alert, calm, relaxed, at ease, curious, absorbed
ACTIVE -	Student is not engaged with material: student actions interfere with self and others, talking is off-task, destructive with materials, out of seat wandering, physically touching/interacting with students not on task; turned away from instructor not listening, fidgeting (>3s), off-task computer work, checking phone	Signs of following emotions (>3s): upset, angry, distressed, frustrated
PASSIVE -	Student is not engaged with material: does not participate in discussions, not focused on work during critique, spends time with materials without purpose (different than exploratory play), eyes closed, slouched or sleeping, unresponsive to instructor's prompts	Signs of following emotions (>3s): sad, drowsy, tired, bored

ENGAGEMENT WITH SPACE signifies aspects of the physical environment which students or instructors are physically interacting or referencing.

TIME SEG.	ACTUAL TIME	INSTRUCTIONAL METHOD	ENGAGEMENT		CONTENT ADDRESSED		ENGAGEMENT WITH SPACE
			Behavioral	Affective			
00		Whole Class Small Group 2 3 4 5 Individual alone Individual w/ instructor	Active + Passive + Active - Passive -	Active + Passive + Active - Passive -	Art/Design	Science	Tables Aquaria Green wall Hydroponics Projector
10		Whole Class Small Group 2 3 4 5 Individual alone Individual w/ instructor	Active + Passive + Active - Passive -	Active + Passive + Active - Passive -	Art/Design	Science	Tables Aquaria Green wall Hydroponics Projector
20		Whole Class Small Group 2 3 4 5 Individual alone Individual w/ instructor	Active + Passive + Active - Passive -	Active + Passive + Active - Passive -	Art/Design	Science	Tables Aquaria Green wall Hydroponics Projector
30		Whole Class Small Group 2 3 4 5 Individual alone Individual w/ instructor	Active + Passive + Active - Passive -	Active + Passive + Active - Passive -	Art/Design	Science	Tables Aquaria Green wall Hydroponics Projector
40		Whole Class Small Group 2 3 4 5 Individual alone Individual w/ instructor	Active + Passive + Active - Passive -	Active + Passive + Active - Passive -	Art/Design	Science	Tables Aquaria Green wall Hydroponics Projector

Appendix B: Interview Protocol

MAKER: Piloting a BioDesign Maker Space and Curriculum for K-12 STEM Learning
Student Focus Group Interview Protocol

"Thank you for agreeing to participate in this research study. We are investigating a new learning setting that identifies the human-nature connection as a way to engage students in STEM learning. Our focus in on the newly built "BioDesign" Makerspace, and the development of curriculum which engages with living materials and natural processes. We are interested in new perspectives on the presence of nature in human spaces, and the power of studio makerspace pedagogy to prepare students to meet social and environmental challenges through art and design + science knowledge inquiry, challenges such as air and water pollution and food security.

We would like to hear about your perspective as a student within the context of this project. I have a set list of questions, but please feel free to also inject other thoughts or let me know if there is a question you want to skip. I will be taking notes and recording our conversation so please let me know if you don't want to be before we begin and we can stop now. This will in no way affect your grade and all your answers will remain anonymous as part of the research project. Because questions are addressed to the whole group, please chime in with an answer whenever you like."

Questions about Art &Science Learning
"Because this space and project were new to everyone, you were a pioneer of sorts in a new kind of arts integration. The next few questions have to do with you as a learner in this space."

1. What made you choose this program?
   Probe: What was your understanding of the program before you came?
   Probe: Were you interested in learning more about art and design?
2. What is your past experience with art and design?
   Probe: Have you taken art classes in school?
   Probe: Have you worked in a makerspace?
   Probe: Have you worked in another sort of studio setting?
3. Where have you had experiences learning about science in the past?
   Probe: Has learning science in this internship been similar to learning science in other spaces?
   Probe: Has learning science in this internship been different than learning science in other spaces?
4. What did you learn about artists and scientists in society from this program?
   Probe: What do you think you learned about artists and designers that you did not know before?
   Probe: If it has, what do you feel like you learned about science or scientists through this process?
   Probe: Did you find any differences in the role of the artist/designer and the role of the scientist in the work you were doing in class?
5. Has your understanding of living systems changed at all through being a part of this project?
   Probe: Did your relationship to nature change throughout the design and implementation of this curriculum?
   Probe: Do you think it is important to study how nature functions?
6. How does what you learned in this program relate to your world outside of school?
   Prompt: Do you think about what you have learned when you are not in the program?
   Prompt: Have you thought about ways you could apply what you are learning in the program to problems you have to address outside of school?
7. Which project did you enjoy working on the most and why?

Questions about the Biodesign Space
"This next set of questions has to do with the physical space in which we were working."

8. What are your impressions of this classroom environment?

9. Rate this space against other classrooms you have worked in. Would you rate it higher, as in better than, or lower?

10. Name three qualities that best describe the vibe of this space.

11. Did you feel that the space was important to your learning?

Probe: Do you think it was important for you to be doing the activities you did in this space?
Probe: Could the learning have happened in a classroom at the MET school?
Probe: What aspects of the room were most important in helping you learn?

12. What aspects of the room did you like the most?

Probe: What aspects of the room did you find most interesting?
Probe: Were there certain aspects of the room that you wanted to look at a lot?
Probe: Were there certain areas that you wanted to be near?

Design and environmental Agency
"This final set of questions gets at how the work in this program may have or may not have changed your ideas about some broader global issues."

13. Can you talk about the best experiences you may have had with environmental education, either in or out of school?

Probe: projects, camps, gardens?
Probe: Why were they the best?

14. Do you feel environmental issues are relevant to your life?

Probe: Do you think it is important to learn about big world issues like global warming, food scarcity or deforestation?
Probe: If so, why?

15. Did participating in this program change the way you see the role of art and design in problem solving around social and environmental challenges?

Probe: Do you think artists and designers have a role to play in tackling big global issues?
Probe: How can artists and designers expertise be helpful in tackling big challenges?

16. Have any of your feelings about your ability to impact the environment changed as a result of your participation in the program?

Probe: Do you think that one person can make an impact on big environmental issues?
Probe: Do you think you'll do anything different as a result of the program?

"Thank you for your time. Do you have any questions or comments about what we have discussed today?"