ASEE's 123rd Annual • Conference & Exposition • New Orleans, LA • June 26-29, 2016

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Paper ID #16976

RTP Design as the Practice of Probability: Engaging Adolescent Girls in Art-Infused Engineering

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Introduction

This paper addresses the marked underrepresentation of women (in particular, women of low socio-economic status) in engineering careers by studying the impact of an arts-infused engineering intervention in the middle grades. Engineering, like the other STEM (Science, Technology, Engineering and Math) fields, has traditionally been perceived as a male domain, whereas the arts and humanities have traditionally been viewed as more “feminine” fields.[1] These stereotypes have been increasingly challenged, including by studies that show girls earn higher grades than boys in all subject areas, at all stages of their K-12 schooling.[2] Yet, in the post-secondary realm, males continue to dominate the STEM fields in terms of educational degrees earned and career paths. This phenomenon has been attributed to various causes, including peer pressure[3], competing values[4], differences in brain structure and functioning[5], systemic patriarchy[6], preconceived notions of engineers[7] and gender stereotyping and identity performance[8]. This mixed methods study examines how adolescent girls make sense of engineering versus visual art as a field of study, arguing that when the two subject areas are integrated, girls develop more accurate understanding of the nature of engineering as well as the nature of art. As a result, they are better able to perceive the expansive, multi-disciplinary potential of engineering. This, in turn, leads them to consider careers in engineering.

Perceptions of Engineers and Engineering

This study begins with the premise that engineering is a widely misunderstood field. Based on this idea, the researchers hypothesized that if pre-teen and teen girls were better informed about the nature of engineering, they would be more likely to pursue it in their post-secondary lives. The fact that engineering is not widely understood has been well documented[9]. Mena and Diefes-Dux attributed this lack of understanding to the expansive nature of engineering’s activities and goals, a quality that makes the articulation of a single, widely comprehensible definition difficult to achieve. They found, however, that common perceptions of engineering—even those held by undergraduate engineering students—were highly reductive, perpetuating the stereotype that engineering is an endeavor only for those who are interested in, above all, math and science[10]. That stereotype reinforces another deeply entrenched, commonly held view that math and science are associated with male, not female, interest and achievement. These stereotypes have been notably difficult to disrupt, particularly during adolescence, when defining one’s gendered identity is a central part of the socializing process of becoming an adult.

Kessels theorized that subject area affinity is deeply connected to adolescent identity performance.[11] Adolescents are keen perceivers of the social meanings attached to subject areas. Those meanings are generally associated with both the subjects’ characteristics (including content) as well as the characteristics of students who are drawn to them. Such social meanings become an important barometer against which youth determine if their subject area preferences are socially acceptable[12]. Thus, the adolescent negotiation of gender identity in relation to subject area preference has lifelong implications for career choice.

Lending credence to this idea, Hannover and Kessels demonstrated that an adolescent’s future career interests are closely tied to how closely they perceive related subject areas to be to their gender identity.[13] With peer group acceptance at stake, the importance of conforming to gender normative identity performances—including subject area preference—for adolescents cannot be underestimated. Research has shown that even though girls have been shown to outperform boys in subject areas traditionally considered masculine (e.g., science and math), they still, by and large, indicate a preference for the arts and languages over STEM subjects[14]. Given these trends, this study used deception to test the idea that if girls believed they were learning art, but were actually learning engineering infused with art, they would become more interested in pursuing engineering, partly due to the mitigation of gendered subject-area stereotype threats. The researchers further hypothesized that stereotype threat would be further reduced when the imaginative, creative, design components of art were actively synthesized with those same dimensions of engineering.

Conceptual Framework

The idea of uniting art and the STEM subjects is not new, and it is undeniably fashionable in the contemporary preK-16 education context. At the same time, scholars and practitioners alike have engaged in an ongoing struggle to define productive relationships between the arts and STEM. The space where the domains intersect is contested—and experienced by practitioners in relation to the demands, methods and belief systems of their respective disciplinary domains. STEM educators face the conundrum of taking time to learn about and leverage the arts' special capacities while responding to the urgent need to prepare their students as members of a STEM literate society. Arts educators face the chronic problem of being under-resourced, misunderstood and positioned as a "handmaiden" to other agendas[15].

Renowned education scholar Shirley Brice Heath argued that engaging the arts and sciences in "an interlocking embrace" (p. 26) could catalyze student learning and create greater likelihood that young people from under-resourced environments would make their way to meaningful STEM careers. Through a series of studies, she found that this art-science embrace was particularly powerful in informal learning settings. In such settings, young people could develop fluency in observing, imagining, practicing, talking and creating in the manner of artists and scientists. In other words, learners were socialized into unfamiliar practices, becoming aware of new ways of thinking, being and doing in the world. The socialization took place through engagement with personally meaningful projects. In order for informal learning environments to achieve this generative quality, they depended on a pluralist approach to the nature of knowledge (multiple ways of knowing) and the diversity of learners' backgrounds. This, Heath argued, would change "empty promises of *possible* futures into the work and play of *probable* futures"[16] (p. 27).

Design as the Practice of Probability has created a conceptual framework through which some of these tensions can be resolved. The study tests this framework as a tool for creating new pathways for meaningful *and probable* participation by girls in the global workforce as engaged, engineering-literate citizens. The framework is based on Constructivist theories of learning and the idea that hands-on exploration constitutes a rich and meaningful knowledge-building process[17]. It consists of three tiers, which are illustrated in figures 1-3 below.

The framework is particularly well-suited to the project's agenda of diversifying (and creating equity within) the field of engineering. In conceptualizing making as thinking-in-action, the framework allows the researchers to adopt a Freirian perspective on knowledge building. Freire and his followers argued that in order to meet the needs of diverse learners, educational institutions must value indigenous, local knowledge (which includes understanding that is gained through making).[18] Connecting content to local knowledge requires educators to support students in finding meaning in classroom-based activities and discourages rote memorization of abstract rules and “facts”. In this way, space is opened for students to display and act on their “funds of knowledge”.[19] Funds of knowledge are the rich body of understandings and metal schema that students construct within their home and community lives. These funds are often not recognized in schools and instead are often devalued, whether implicitly or explicitly, when they derive from marginalized cultural contexts.[20] This study views funds of knowledge expansively and includes gender identity performance as one of many possible funds of knowledge students bring to the classroom. Therefore, we position girls’ identities, including identity performances associated with a subject area preference for art, as a resource for helping them find meaning in engineering-related educational experiences.

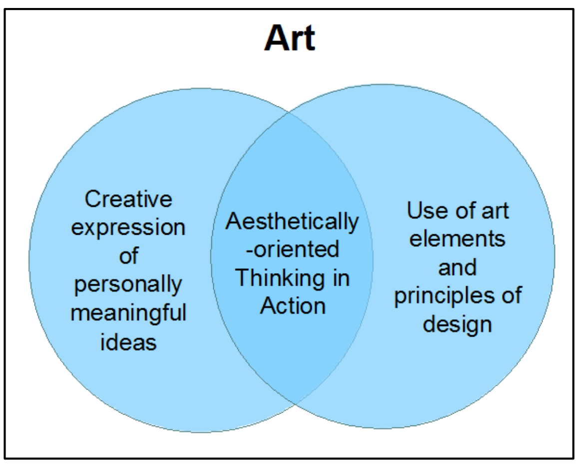

Figure 1: Tier 1 of the conceptual framework

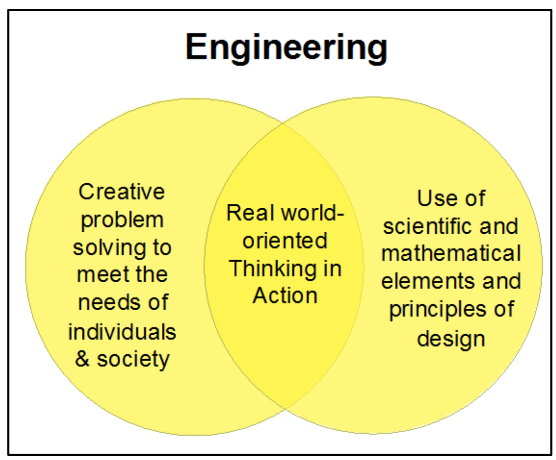

Figure 2: Tier 2 of the conceptual framework

Tiers 1 and 2 of the framework explain unique, yet interrelated qualities of art and engineering, giving primacy to their shared perspective that knowledge is constructed through active, design-oriented making. Figure 3 illustrates how the different forms of thinking-in-action can maintain disciplinary integrity, while creating a fertile interdisciplinary contact zone.[21] The researchers argue that this contact zone can make engineering more relevant to the lives of girls, resulting in a greater likelihood of future engineering probabilities.

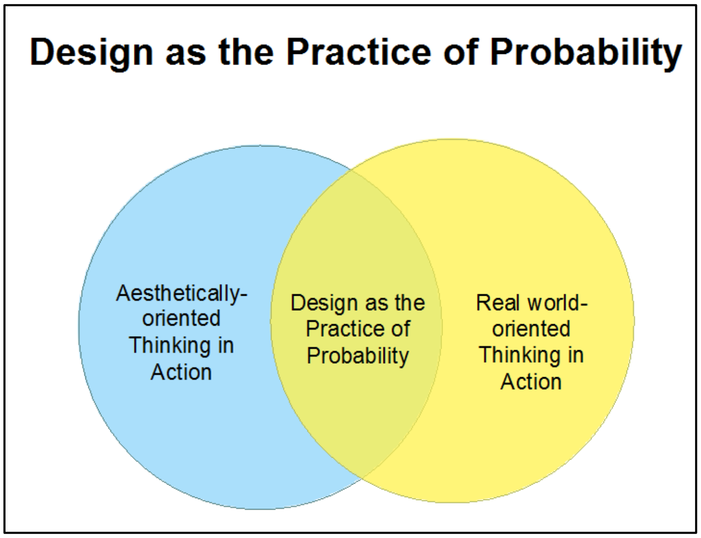

Figure 3: Tier 3 of the conceptual framework

Many pathways to engineering are possible when art is united with engineering through design. The researchers acknowledge, however, that they all necessitate the development of advanced visual spatialization skills. Yet, such skills are chronically under-developed in the majority of first-year undergraduate engineering students.[22] Because Uttal et al. demonstrated that spatial skills can be effectively learned,[23] advancing knowledge about *how* those skills can be learned is critically important in reducing barriers to girls' participation in engineering. Along these lines, using visual art to support learners' visual spatialization capacities has demonstrated promise in several studies.[24] In addition, visual learning has been shown to improve depth of STEM content knowledge by making abstract concepts accessible to a wide range of learners.[25] Because art's purpose is the representation of abstract ideas through visual forms, uniting the disciplines through design holds specific promise for enhancing the probability of girls' long-term engagement with engineering.

Methods

Participants and Setting

This study's participants are comprised of 27 middle school students (6th, 7th and 8th grades). All students attend a semi-public, non-charter STEM (Science Technology Engineering Math) school located in a large urban center within a Midwestern state. The school is open to all students in the state, but most reside in the city where the school is located. The school is administered by a governing body comprised of representatives from school districts throughout the state, this study's university partner and industry collaborators. As a school of choice, all students have elected to attend the STEM-focused school. Therefore, assuming that all participants have a greater-than-average bias toward pursuing STEM-related post-secondary pathways is reasonable. The socio-economic demographics of the school's student body are described in figure 4.

	# Students	% Student Body
Female	161	51%
Male	154	49%
Caucasian	154	49%
Black/African Descent	87	28%
Latino/Hispanic	15	5%
Asian	32	10%
Native American	0	0
Multi-Racial	27	9%
Free or Reduced Lunch	84	27%
ESL	0	0

Figure 4: Study Site Middle School Demographic Data (provided by the school)

The beginning demographic data for the art club participants and the engineering club participants are illustrated in figures 5 and 6, respectively.

	# Students	% of Art Club Students
Girls	20	74%
Boys	7	26%
Caucasian	15	56%
Black/African Descent	3	11%
Latino/Hispanic	0	0%
Asian	5	19%
Native American	0	0%
Multi-Racial	4	15%
Free or Reduced Lunch	N/A	N/A
ESL	2	7%

Figure 5: Art Club (Treatment Group) Demographic Data (student self-reported)

	# Students	% of Engineering Club Students
Female	3	20%
Male	12	80%
Caucasian	7	47%
Black/African Descent	2	13%
Latino/Hispanic	1	7%
Asian	2	13%
Native American	1	7%
Multi-Racial	0	0%

Free or Reduced Lunch	N/A	N/A
ESL	2	13%

Figure 6: Engineering Club (Control Group) Demographic Data (student self-reported)

As shown in figures 5 and 6, the demographic make-up of both clubs' members aligns with the overall composition of the school body, with the very noteworthy exception of gender. As the literature has demonstrated and this study's researchers accurately hypothesized, when offered the choice between art and engineering learning opportunities, by-and-large girls chose art whereas boys chose engineering.

The treatment group experienced attrition over the course of the year and will finish the year with 14 females and 5 males.

Research Design and Activities

To test their hypotheses that girls could be better engaged in engineering through the integration of art (thereby increasing their knowledge about engineering and their engineering-related spatial visualization skills), the researchers created a quasi-experimental design study. The design involved two year-long, weekly after-school clubs within the STEM middle school, with one club focused on engineering (the control) and the other on (engineering as) art (the treatment). None of the students, nor their parents, knew that the art club was part of an engineering education initiative. (Participants will learn of the engineering agenda at the conclusion of this multi-year study.) In order to mitigate validity threats to the research that are attributable to adolescent peer pressure and gendered identity performance and because risk to the research participants was minimal, it was determined that the deception was warranted, helping the researchers to more accurately determine causal relationships between gender identity and engineering engagement.

The above quantitative approach was supplemented with qualitative methods. Data collection involved primarily small focus groups, one-on-one semi-structured interviews and participant observation. As we are currently in the midst of the first year of this multi-year study, this interim analysis will address only students' attitudes and will present early findings to inform the remainder of the research project.

Control group. The engineering club was advertised synchronously with the art club (and all other after-school offerings) at the beginning of the school year, including at parent-child orientation meetings. Fifteen students selected the engineering club and attended weekly after-school meetings. The meetings were run by engineering faculty and their graduate and undergraduate students from the partner university. No visual art was introduced.

Treatment group. A total of 27 students enrolled in the art club. This figure represents nearly double the enrollment of the engineering club. Art club activities were centered origami, the Japanese art of paper folding. This medium was chosen in order to synthesize the arts learning with a specific engineering field of study: DNA origami. Engineering and interdisciplinary education researchers, along with undergraduate and graduate engineering students, art and art education undergraduate and graduate students and art specialists, collaborated in the planning and implementation of all art club activities.

Activities. Because origami as an art form can be mechanistic (somewhat analogous to memorization) for novices, the partners adopted a theme-based approach to the content. This approach encourages conceptual connections across disciplines and is consistent with the content standards in all of the STEM disciplines. (By outlining a sample of weekly activities, learning goals and methods, figure 7 provides a glimpse into how this theme-based integration strategy was enacted within the art club.) The theme-based approach was intended to support origami-related learning experiences that prioritize students' personal expression and meaningful engagement with the design process. To that end, origami was used, not as an end in itself, but as a launch pad a variety of paper-based and non-paper-based materials explorations. (See figure 8.) Those explorations have been linked to the explicit through lines of individual artistic vision, (including repetition of form, variation, modularity, scale, and more), meaning-making and conceptual, installation art. The students have been guided to the theme of "identity" which was linked to principles of DNA origami. The origami medium was also particularly well suited to the development of spatial visualization skills, as it requires students to continually convert flat (two-dimensional) sheets of paper into three dimensional forms (and vice versa).

Club Session	Activity	Learning Objectives	Art Principles	Corresponding STEM Principles	Specific Techniques and materials	Activities
1	Frog, crane, matsu box	Engagement, community building, retention	understanding basic origami and art principals, Color palatte	Team building; core principles	Range of pre-cut papers in pre-determined palette. Constrain palette, vary size & texture.	Intro & snacks, what is art? Origami basics. Choose color & object. Make one for practice, one to take home.
2	Paper coloring exploration	engagement, community building, retention, think beyond the box about materials, color theory	Intro to color wheel.	Experimentation prototyping, material properties	liquid water color, food coloring, tea, salt, saran wrap, sponges, fixative, mod podge, acetone, different types of paper	Group one: folding frog with different papers. Bring binder with random origami folds for them to look at/work with if they get done early. Group 2: fold and unfold. Paint different squares but no brushes (blow it with straws.) Introduce color wheel and discuss "next door neighbor" vs "across the street" colors.
3	Origami Boat I	Team Building, craftsmanship, engagement, introduction to art materials, methods and principles/elements	Art Elements: Shape/Form; Principles: Patterning (repetition)	Engineering Design Process. Geometry and connectivity of smaller parts will determine bigger parts (assembly)	wax paper, vellum, paper bags,	Look at all the cool things you can do with origami (bring examples)! Fold origami sail boat. Discuss type of fold/necessary folding technique. Discuss form and general art principals.
4	Refold boat and discuss color placement. Finish Old Origami, Crane and Crane Challenge, Crane Project	Team Building, craftsmanship, personal expression & meaning-making; introduction to installation art	Art Elements: Shape/Form; Color	Materials; Design (boat); & Function. Did it float?	Range of pre-cut papers in pre-determined palette. Frog, crane, matsu box. Constrain palette, vary size & texture.	Introduce the idea that art is a meaning-making, expressive process. One way to communicate meaning is through the thoughtful use of color. Fold new origami sail boat out of papers chosen/created with a specific color palette. Introduce the idea of complementary, analogous and tertiary colors as well as hue, shade and tint. Create installation of boat on water. Introduce the ideas of audience and visual communication. Intro 1000 crane challenge.
5	Presentation of Sketchbooks for documentation. 12-unit sonobe ball	Team Building; Reverse Engineering; Pattern recognition	Art Elements: Scale; Patterning (Parts to the whole)	Modular Designs; reverse engineering	Give students a 12-unit sonobe ball, reverse engineer (deconstruct) to create patterns. Correct color pattern for each pyramid is extra -- must plan ahead and be able to spatially visualize this.	Presentation of sketchbooks; In teams study 12-unit sonobe ball. Instruct that are allowed to take it apart, but must document how in enough detail to be able to fold one of their own in future.
6	senobe balls, small groups, sketch books, figure out, take notes without instructor input	Continue with Reverse Engineering.	Art Elements: Line (straight vs. curved)	Modular Designs; reverse engineering	Continue with sonobe ball deconstruction and pattern creation. Build their own sonobe ball.	Using their documentation only, create their own 12-unit sonobe ball. Discuss role of documentation & level of detail needed for successful recreation.

Figure 7: Sample of art club activities

Data Collection and Analysis

Quantitative data. The quantitative data collected thus far has been obtained through pre-test surveys, which were administered to treatment and control groups. The survey instruments included *The Modified Attitudes Towards Science Inventory*,[26] which is a 25-question, 5-point scale assessment designed to evaluate student attitudes in the domains of engagement and attitudes toward science. In its published form, the survey has been adequately tested for reliability and validity. The instrument's subscales are as follows:

1. Perception of the Science Teacher (3 items)
2. Anxiety toward Science (5 items)
3. Value of Science in Society (5 items)
4. Self-concept of Science (5 items)
5. Desire to do science (7 items)

Since the study involves deception, we did not want the students to question taking an assessment that only had science related questions. Therefore, we adapted the inventory to include all questions pertaining to subscales 2 and 4 above, and only 1 question from subcales 3 and 5. In addition to these 12 questions, we repeated all 12 questions replacing the word "science" in each with the words "art" and "math." The resultant 36-question inventory also had the same initial demographic data. Data were analyzed by first reversing the scores for the negatively worded statements then separating responses by gender and by topic (science, math, art) and then by subscale (1-5 shown above).

	Subscale	Gender	Average PRE (std dev)	Average POST (std dev)	% Difference	p value
ART CLUB Number Pre F = 20 Pre M = 7 Post F = 14 Post M = 5	Anxiety Toward Science	F	1.96 (0.82)	1.70 (0.47)	-7.1	0.15
		M	1.80 (0.50)	1.80 (0.35)	0	0.5
	Self-Concept of Science	F	3.87 (0.96)	4.04 (0.67)	2.15	0.28
		M	4.03 (0.60)	4.08 (0.33)	0.62	0.43
	Anxiety Toward Math	F	2.21 (0.96)	2.22 (0.74)	0.23	0.49
		M	2.34 (0.89)	2.04 (0.90)	-6.85	0.29
	Self-Concept of Math	F	3.33 (0.60)	3.39 (0.74)	0.89	0.4
		M	3.14 (0.43)	3.88 (0.86)	10.54	0.04
	Anxiety Toward Art	F	1.75 (0.38)	1.81 (0.69)	1.69	0.36
		M	2.00 (0.62)	2.08 (0.82)	1.96	0.43
	Self-Concept of Art	F	4.15 (0.62)	3.40 (0.91)	0.001	0.23
		M	3.74 (0.43)	3.76 (0.64)	0.48	0.27
ENGINEERING CLUB Number Pre = 15 Post = 12	Anxiety Toward Science	All	1.62 (0.42)	1.47 (0.51)	-4.84	0.09
	Self-Concept of Science	All	4.20 (0.62)	4.55 (0.75)	4.00	0.03
	Anxiety Toward Math	All	1.65 (0.49)	2.18 (0.45)	13.84	0.02
	Self-Concept of Math	All	4.38 (0.74)	4.15 (0.41)	-2.70	0.05
	Anxiety Toward Art	All	2.50 (0.55)	2.72 (0.66)	4.21	0.13
	Self-Concept of Art	All	3.45 (0.39)	3.15 (0.44)	-4.55	0.05

Figure 8: Comparison of Pre and Post Modified Attitudes by Gender and Club.

Qualitative data. For the treatment group, qualitative data collection has thus far included observations, a focus group, field notes, artifacts such as photographs and videos of students participating in the clubs and student artworks. The focus group consisted of four females who participated regularly in the art club in the first half of the academic year and then decided to leave the club at the beginning of the second half (shortly after returning from winter break).

Discussion

Our initial analysis is somewhat consistent with what we expected to find at this early point in our multi-year study. First, in terms of students' attitudes toward science (see figure 8), there were notable differences between females and males in both clubs. On the 5-point scale, the average science anxiety score for girls in the art club was the highest (1.96). As expected, the boys' in both groups scored lower on the science anxiety scale compared to the girls in the art club. Also as expected, the boys in art club (1.80) had higher science anxiety than the engineering club (1.62).

The science self-concept scores across both genders in the art club are nearly identical, and higher in the engineering club. At this point in the study, the researchers hypothesize that this finding could be attributed to the fact that all of the students have specifically chosen to attend a STEM school. Therefore, we would expect to see a more robust self-concept among all of the student body members than we might see in a non-STEM school. This hypothesis will be tested in the following school year, when our study expands to a second middle school. The second school is not a STEM school, not is a school of choice.

As with the science anxiety scores, math anxiety scores for art club participants, both male and female, were higher than those of their engineering club counterparts. Conversely, both male and female art club participants had lower math self-concept than that of the engineering club participants. These findings, as illustrated in figure 8, align with our expectations.

The art attitudes scores were similarly predictable. Students, both male and female, who selected the art club had lower anxiety about art and higher self-concept about art than did students in the engineering club. (See figure 8.) When analyzed according to gender identity, the data revealed that girls in the art club had the lowest anxiety and highest self-concept about art out of all the students (both art and engineering). This was exactly what we had expected. The highest anxiety and the lowest self-concept about art across all four groups was experienced by the engineering club.

Also in figure 8 are the post data by gender for the art club, and as aggregate for the engineering club since there were only 2 females still participating in the engineering club. In the art club, there were improvements in self-concept in science and math and decreases in anxiety in both. In fact, the increase in self-concept in math for the males was statistically significant. The engineering club showed a statistically significant increase in science self-concept and a statistically significant decrease in math self-concept. Engineering also showed a statistically significant decrease in science anxiety and a statistically significant increase in math anxiety. The changes in math for the engineering club were surprising and may be due to a concurrent increase in the difficulty of math being covered in their formal math education content.

While we have focused analysis in this first year of the study on the quantitative data obtained primarily through pre-testing, several important themes have begun to emerge from the focus group. Those themes were related to the girls' reasons for leaving the club in favor of free playtime with board games, cards and general social interactions. The reasons included disappointment that the art club didn't have enough art ("it felt too science-y") and there was too much direct instruction. Three of the four students stated that they had expected to do more painting and drawing. Their favorite activities had included painting and actual origami folding, although they felt that too much origami would become "boring". Finally, two of the four students expressed that small group design challenges and collaborative art making experiences were not enjoyable due to group dynamics, particularly in terms of group members who "took over" the projects. The other two students in the focus group enjoyed the design challenges and were not in the same small groups as the two students expressing dissatisfaction with that component of the club. Interestingly, all four students were female, and the one student who had the most experience in art outside of the club was one of the four. That student had taken several extracurricular art courses at a local art college.

Implications for Continuing and Future Research

The *Design as the Practice of Probability* study seeks to contribute to the literature on engaging under-represented populations in engineering. In this early stage of the study, we have focused on several gendered dimensions of subject area self-selection, attitudes and self-perceptions within an informal learning context. Our findings thus far have indicated several unexpected trends that merit further investigation. Limitations of this study include the fact that the full attitudes survey that we administered has not been validated or shown to be reliable, as we modified the original instrument in order to maintain the deception necessary to carry out the research design. As the study progresses, qualitative data will be used to further probe any areas that might require further elucidation due to the survey design process.

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