



Aesthetics and Engineering: A Path to Transformative Learning and Professional Confidence

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By Hugh Scribner, Katherine Goodman, Jean Hertzberg

Abstract - Background: *In most engineering classes, students are required to focus on the technical side of engineering, the part with all the equations and science. Perhaps because of this focus on analytical thinking, prior studies have found that many students exit their engineering classes with a negative affect towards the topics discussed over the semester and as a result feel alienated from their peers. **Purpose:** In response to these findings, an engineering technical elective was designed to focus on aesthetics, to allow students to use their engineering knowledge in new ways. This study was initiated to understand the influence of this course on student affect. **Design:** By examining the experiences and engineering identities of students in such a course (n=29), this study demonstrates that these students not only begin to observe aspects of engineering in the world around them, but also begin to feel more like engineers. To gauge these effects, a 68-item questionnaire was designed and validated to measure the transformative experience and engineering identity. **Results:** A comparison of pre- and post-course responses to this survey indicate that 40% (n=12) of the students who were enrolled in this course experienced a positive gain in expansion of perception. Furthermore, the average student in the course reported a 23% gain in confidence towards their engineering skills. However, the survey was administered in Spring 2021, and a pre-post comparison of the word count of three of the four open response items shows a decrease of one standard deviation, or 26%, in response length across responses, suggesting significant end-of-semester stress and/or survey fatigue. **Conclusions:** Despite anomalies related to the pandemic, it appears that a course focused on aesthetics can promote both increased perception of engineering concepts in the broader world, which we deem to be a central goal of learning experiences.*

Introduction

Typically, engineering classes focus almost entirely on the *how* of engineering, teaching students to answer questions like “how to calculate the principal stresses in a cantilevered beam”, “how much the pressure in a vessel increases when heated 10° C” or “how fast a fluid flows through a pipe.” While it is important that students can accurately solve such problems to be successful engineers, this pedagogy neglects to take the time to show students the beauty in the physics and engineering concepts they are laboring to learn. Due to this neglect, many engineering students complete their engineering courses with the ability to solve complex engineering problems but no desire to further explore the topics they have learned. In fact, in some cases STEM students leave their classes feeling that the topics that they learn about are unrelated to the real world and frivolous. Because of this emotional response it is becoming common to see students graduating from university with degrees in STEM but no plans to pursue a career in a STEM field[1].

Although the Mechanical Engineering curriculum at the University of Colorado has a significant emphasis on design, all the formal design experiences offered to students are team based; students

are never asked to carry out a design-build project from beginning to end on their own. This can lead to students specializing in a particular design role and avoiding others.

To address these issues, a new engineering course was introduced at the University of Colorado, Boulder, Aesthetics of Design (AesDes). AesDes is a design course where students are asked to use their engineering skills to create aesthetics-based designs. The creators of this course hope that these projects will promote an affective gain towards engineering by providing students with a transformative learning experience [2], [3] and an opportunity to view themselves as engineers. More information on the AesDes course and examples of student work can be found on the course webpage <https://www.aesdes.org/>.

The AesDes class was first taught at the large public research university in 2014 and has been taught every spring semester since. Although the class is taught through the mechanical engineering department students from all engineering disciplines are allowed to enroll in it. To measure the effects AesDes has on its students' matching entry and exit surveys were developed which student participants take prior to and after taking AesDes. A previous study was performed on the initial offering of AesDes to determine the effects on the students. In this study, it was found that AesDes was successful in what it set out to do: students were experiencing an affective gain towards engineering [2], [4]. The study also suggested an improvement in engineering identity. While the initial version of AesDes performed as intended, many aspects of the course have changed over the last eight years due to student feedback, among other factors. Among these changes are the following: the class is now taught by only one instructor instead of several, the course is taught during the spring semester (16 weeks) instead of the Maymester session (3 weeks), and general shifts in lecture content. The pandemic also necessitated a reduction in team interactions. Because of these changes, the question is now posed, "does AesDes still provide students with the benefits despite variations in course structure and motivations for student enrollment?" To answer this question, the AesDes pre- and post-surveys have been revised to measure such effects. In this iteration of the survey the primary research questions are centered around affect and identity:

1. Do students who take AesDes leave the class with a new or enhanced perspective on the world? This is what is known as a transformative experience.
2. How, if at all, does AesDes affect the engineering identity of its students?
3. Are students who take AesDes gaining a deeper understanding of the relationship between design and aesthetics? In other words, do students experience a cognitive gain?

Background

The two key constructs that this study aims to measure in the AesDes students are the transformative experience, as defined by Pugh [3] and engineering identity, as defined by Stevens et al. [5]. The first of these constructs, the transformative experience, can be characterized by three main factors: expansion of perception, motivated use and affective value. These factors can be observed as a student's ability to perceive their learning in the world around them, doing so without being prompted and experiencing positive emotions while doing so. We hypothesize that a

transformative experience can be fostered by coursework requiring creativity and aesthetics. In the process, a student will see how their engineering learning applies to the real world, and as a result will begin to feel like they are qualified to pursue STEM fields.

This event will be indicative of the second construct, engineering identity. For the purposes of this study engineering identity is defined as set out by previous work by Stevens et al. [5] : an individual's belief that they ARE an engineer. As Stevens explains, this shift towards identifying as an engineer is often accompanied by changes in disciplinary knowledge, and as a student navigates through the education process., For example, a student will likely have a strong sense of engineering identity when they feel that they are able to do tasks they associate with those performed by a successful engineer, are identified as an engineer by their mentors, peers, and family, and have passed certain courses and graduated [6]. It should be noted that while this study focused on the engineering identity of mechanical engineering students, it did not focus on their identity as a *mechanical* engineer specifically.

These constructs were selected because the study of the initial offering of AesDes [2] showed that students did indeed experience a positive shift in affect and had transformative experiences through taking the course. Another result from that study was a student self-reporting that while taking the AesDes class they discovered that for the first time in their education, they “felt like an engineer”. Because of this student's observation the scope of this study was expanded to include engineering identity.

Methods

To measure the effects of AesDes on the 2021 class (n=29, matched pre/post), a 68-item survey was developed and administered in the 2021 spring semester. This questionnaire, called the AesDes survey, had items adapted from older versions of the AesDes course survey, questions taken from the previously validated APPLES survey [7], and several questions that were developed for this iteration of the survey. A complete version of the AesDes Survey can be seen in Appendix A. The AesDes survey was administered to students at the beginning and ending of the AesDes class. No testing was performed on students after their completion of the AesDes class nor on students who did not enroll in AesDes.

The APPLES survey was selected for use as a basis for the AesDes survey because it provided a variety of measures that could be used to detect engineering identity that had been validated against a large sample of senior and first year students [7]. While APPLES provided a basis for evaluating engineering identity in students, additional questions were also needed for two further tasks. First, the survey needed to be able to measure affect, or the transformative experience, in students. Secondly, it needed to be able to relate shifts in student confidence back to AesDes course content, such as aesthetics and design. Questions 5, 7, 8, 9, 10, and 11, address this first concern, as each question asked students about their feelings towards their coursework and how it applied to their daily lives. Questions 3, 4, 6, and 12 were included to address the second issue by focusing in on how aesthetics specifically related to the any shifts the student may have experienced.

One question that necessitates specific explanation is Question 8, which asked “How does making things on your own make you feel at the beginning of the process? Why does it make you feel that way?” This question was chosen to focus specifically on the beginning of the process for two reasons. First, it was desirable for the question to specify which part of the design process the

student should talk about to minimize the likelihood of student misinterpretation and encourage consistency across responses for ease of comparison. Secondly, by emphasizing the beginning of the process it was hoped that more insight could be gained towards how students feel about ideation and initial planning of a project, topics that students have reported difficulty with.

A description of how each question mapped to a given construct is provided below in Table 1. On the questionnaire, Questions 1, 2, 3, 12, 16 were each multi part items, and are listed twice in the table when these questions mapped to different, sometimes multiple constructs. Additionally, Question 13 is not listed as it was used to validate an item in Question 12. Question 14 is not listed as it was used as a logic question on the survey to sort student responses. It should be understood that the mapping of these questions to the central constructs of this study is not perfect and will be iterated upon in future studies

Transformative experience
I. Expansion of perception
Question 9** – Are aesthetics important to the career you intend to pursue after graduation? Explain. Feel free to include what career you are interested in.
Question 10** -- Are aesthetics important in your non-professional life? Explain.
Question 11 – How important are aesthetics to your studies?
II. Motivated Use
Question 7 **-- What motivates you when choosing an aesthetic while designing something?
Question 12 – Presurvey wording: What influenced your decision to enroll in this course? Postsurvey wording: What motivated you to achieve in this course?
III. Affective Value
Question 5 – Rate your agreement with the following statement: I am interested in a career that is predominantly focused on design.
Question 8** – How does making things on your own make you feel at the beginning of the process? Why does it make you feel that way?
Question 12 – What influenced your decision to enroll in this course? This is a class about making/building things I want to learn about industrial design I want to learn to make attractive designs This is the only course including art I could take for my degree I expect this class to be less difficult than my other classes I need an elective to fit my schedule I want a course that allows creativity I want to take as much design as I can This course looks like fun I want to take a class taught by Professor (Professor’s name) I think this class will help me build my resume Other
Engineering Identity
I. Disciplinary Knowledge
Question 1* – Rate yourself on each of the following traits as compared to your peers. We want the most accurate estimate of how you see yourself : Self-confidence (social) Leadership ability Public Speaking ability Math ability

Science ability
Communication Skills
Ability to apply math and science principles in solving real world problems
Business ability
Ability to perform in teams

Question 2* – How important do you think each of the following skills and abilities is to becoming a successful engineer?
Self-confidence (social)
Leadership ability
Public Speaking ability
Math ability
Science ability
Communication Skills
Ability to apply math and science principles in solving real world problems
Business ability
Ability to perform in teams

Question 3 – Rate yourself on each of the following traits as compared to your peers in your classes. We want the most accurate estimate of how you see yourself. Creativity
Aesthetic design
Functional design
Drawing ability
Manufacturing skills
Critiquing ability
Ideation ability
Appreciation for aesthetics
Ability to identify major design movements

Question 4 – The final for this course is to complete an aesthetics-based design project. Rate your agreement with the following statement: I am confident in my ability to succeed on such a project.

II. Identification

Question 15* - We are interested in knowing why you are studying engineering. Please indicate below the extent to which the following reasons apply to you:
Technology plays an important role in solving society's problems
Engineers make more money than most other professionals
My parent(s) would disapprove if I chose a major other than engineering.
Engineers have contributed greatly to fixing problems in the world
Engineers are well paid
My parent(s) want me to be an engineer
An engineering degree will guarantee me a job when I graduate
A faculty member, academic advisor, teaching assistant or other university affiliated person has encouraged and/or inspired me to study engineering
A non – university affiliated mentor has encouraged and or inspired me to study engineering
A mentor has introduced me to people and opportunities in engineering
I feel good when I am doing engineering
I like to build stuff
I think engineering is fun
Engineering skills can be used for the good of society

III. Navigation

Question 6 – Rate your agreement with the following statement: I believe that I am capable of successfully pursuing a career that is predominantly focused on design.
Question 15* - We are interested in knowing why you are studying engineering. Please indicate below the extent to which the following reasons apply to you: (see above for choices)

*Table 1: Mapping of survey questions to constructs. * Item is taken from the APPLES survey [7]. ** Item was free response*

Students in the AesDes course were sent an email invitation at the beginning and end of the semester to participate in the study and to take the AesDes pre- and post- surveys. Students were not required to complete the survey but were given ‘participation points’ for completing the survey. Additionally, students were invited over a Slack channel to participate in cognitive interviews to validate the pre- and post- survey. Overall, there were 34 students enrolled in the course. Thirty-three pre-survey responses and 30 post survey responses were received. From these responses, 29 pre/post responses were matched and were analyzed. Additionally, six students were interviewed to validate the survey (n=6). More specific details regarding the validation interviews are discussed in the Validation section.

Data Analysis

Each of the multiple-choice items on the AesDes survey were posed on a 5-point Likert scale. It is common for the distance between points on a Likert scale to be interpreted differently by each respondent, meaning that all the data collected was ordinal [8]. Because of this, a Wilcoxon Signed Rank test was selected to compare Likert responses [9], while the Student’s t-test was used for all ratio type data.

The open response items on the AesDes survey (Questions 7, 8, 9, and 10) were coded using an emergent coding scheme. Furthermore, while being coded, these responses were also categorized for demonstration of gains in each of the six constructs central to this study: Affective Value, Motivated Use, Expansion of Perception, Disciplinary Knowledge, Identification, and Navigation. A detailed explanation of this coding scheme can be found in Appendix B.

Validation

After administering the survey, it was important to validate it. To do this, three primary methods were employed. The first was to calculate Cronbach’s alpha coefficients for each of the questions taken from the APPLES survey and to confirm that no validation was lost in the adaptation of the questions to the new format. Additionally, responses to each of the free response questions on the AesDes survey were coded to confirm that students correctly interpreted each of the questions. Finally, in the cognitive interviews, students were asked to sit with a researcher and read through the AesDes questionnaire, define the meaning of each of the questions, and then answer each question and explain their reasoning. This was done to confirm that students were not providing responses based on socially desirable response bias or misinterpreting any of the multiple-choice questions.

After validating the questionnaire there was no significant loss in validation for the questions taken from the APPLES survey. In Appendix C the Cronbach’s alpha (α) for each question taken from APPLES is included, as is the same value for the AesDes pre-survey. It was found that in some categories the AesDes survey outperformed the APPLES survey and in others it under performed, losing some validation. However, this loss was not enough to reduce any of the coefficients below 0.6; therefore the survey is still consistent to an acceptable level.

Once the Cronbach's alpha coefficients were calculated, the free response questions were coded for misinterpretations. Among these questions it was found that that majority of students did understand what was meant by each question. On the post survey a small number (n=2) students responded to Question 9 twice instead of responding to Question 10. This was likely due to students rushing through the survey at the end of the semester rather than misinterpreting the question. This is further supported: the same students correctly interpreted Question 10 on the presurvey. The other source of error in the free response was several students interpreting Question 8, "How does making things on your own make you feel at the beginning of the process? Why does it make you feel that way?" as "How does making things on your own make you feel?"

An example of this is seen in this response to Question 8 by Subject 13.

"It makes me excited. I love building things and working with my hands. It is rewarding and satisfying to work with a material to turn it into something that is much more useful and rewarding."

The final method that was used to validate the AesDes survey was a series of cognitive interviews. Six students were interviewed (n=6); four students participated in validating the pre survey (n=4) and two students volunteered to be interviewed for the post survey (n = 2). Students who volunteered to be interviewed were paid \$15 for pre-survey interviews and \$20 for post-survey. No student was interviewed for both the pre- and post-survey.

In these interviews not many misinterpretations occurred. The primary misinterpretations that occurred were students not understanding the meaning of the word "ideation" and interpreting "self-confidence (social)" as meaning self-confidence in general. It was expected that students would interpret "ideation" as their "ability to generate ideas to help solve a problem", while many interpreted it to mean creativity, or the ability to devise unique, original ideas. Likewise, students were expected to define "self-confidence (social)" as their confidence in social interactions, rather than their confidence in general life experiences.

A pattern that emerged in the analysis of the AesDes survey was a general saturation in student responses to each of the questions on the survey; responses were pegged at one end of the scale. Evidence of this saturation is discussed later in the results section. In their responses to many of the questions, it was found that students generally had a strong interest in aesthetics and design. This meant that it was difficult to detect significant positive shifts across student responses.

Results

Transformative Experience

The AesDes survey assessed the transformative experience by measuring the three indicators: expansion of perception, motivated use, and affective value. The findings are presented below.

Expansion of Perception

Expansion of perception was measured by Questions 9, 10, and 11, as shown in Table 1.

It was found that the responses to Question 9 were positively saturated, as 51% (n=15) of the students who came into the class gave responses like the following on the entry survey:

“In the engineering field, even though aesthetics is rarely mentioned in any textbooks or courses, obviously it is an important factor when it comes to design. Yes, aesthetics are obviously important in design and I plan to work in an engineering field that will surely involve extensive design.” (Subject 12)

“I believe that aesthetics will absolutely be important to the career I intend to pursue, as I would really like to go into engineering design. There are a few different areas of design that I am interested in, but I especially would like to work in automotive design. While there are a lot of well-designed in parts that will never be seen by most people, I appreciate it when the lesser seen part still look good. Of course, the aesthetics of the more visible parts of a car are essential.” (Subject 14)

“Very important, I [am] pursuing a career in human-centered design. My first job after college is as a Footwear Concept Engineer at Nike!” (Subject 11)

In comparing pre/post responses to Question 9 only 14% (n=4) of students demonstrated a gain towards their perception of aesthetics in their professional lives across responses. This was indicative of the post responses also being saturated, with 65% of the student respondents giving positive responses regarding their view of the relationship between aesthetics and their careers. Meanwhile, 6% (n=2) saw a loss or negative change while 80% (n=23) experienced insignificant or no shift at all. Examples of responses that exhibited a positive shift are included below.

Pre survey	Post survey
No, as of right now I don't know what I want to do so I don't know if aesthetics will be involved. (Subject 18)	“Yes, I want aesthetics to always be subtly present in my design goals. One way I can do this is to learn the design movements even better so that they come more automatically. (Subject 18)
“I'm not sure what specific career I will pursue, but as long as it's engineering, I'm fine with it.” (Subject 23)	“I think it is somewhat important because beside functionality, aesthetics is also a part of engineering that makes a design preferable.” (Subject 23)

Table 2: Pre- and Post-survey responses to question 10 exhibiting a positive shift in student expansion of perception.

In each of these responses students perceived aesthetics as being important to the careers that they either currently were in or were pursuing. 86% (n=13) of the students who exhibited these responses were interested in careers in engineering design, which is a field that is heavily influenced by aesthetics.

At the same time, there were also students who came into AesDes who were pursuing careers where aesthetics are considered frivolous and unimportant. However, it should be noted only 7% (n=2) of responses demonstrated this trend. Such responses on the pre-survey were:

“Aesthetics are not important to the career I am pursuing after graduation. Immediately after graduation I'm taking a position to work on nuclear reactors for the military, so there isn't too much concern with the aesthetics. Outside of that I am interested in working as a

test/launch engineer for a company working in the space industry, so aesthetics isn't the primary concern.” (Subject 4)

“If I end up pursuing systems engineering as my career path is developing, I will be a strong support and contributor in the design process. However, the main design part will depend on the technical leads in hardware design.” (Subject 26)

In contrast to the results of Question 9, Question 10 (a better marker of expansion of perception) it was found that 40% (n=12) of students experienced a gain in how they saw aesthetics in their day-to-day lives. Responses that demonstrated this gain are shown in Table 3.

Pre survey	Post survey
“Somewhat, I suppose I enjoy making things look aesthetic; at least organized and I like aesthetically pleasing things like nature. However, I don't really take time to like design things or make art in my free time. I am really into rock climbing though, which I feel like definitely in a way plays with aesthetics, as certain climbs are more aesthetic, or the movement is more satisfying, and I guess that makes them more desirable to me to do.” (Subject 3)	“Yes! I love aesthetics, for example I spend a lot of time on my personal aesthetic with like my style, living space, and social media.” (Subject 3)
“For my personal development as a CAD designer and aspiring artist, 100% important. I'm taking this class for me and my personal pursuits, not for my career.” (Subject 17)	“Aesthetics are very important in my [nonprofessional] life, through personal projects, graphic design for my band and even in video games such as Minecraft.” (Subject 17)
“Yes, I like when things look and feel “nice”. In some ways I think I'm willing sometimes to accept a slight lack of functionality for a bump in aesthetic. (Case and point, I like apple products more than windows)” (Subject 24)	“Yes I chose products based on aesthetics all the time!” (Subject 24)

Table 3: In the table above are paired pre- and post-survey responses to Question 10

Of the remaining students, 10% (n=3) experienced a negative shift, with the remaining 50% (n = 14) of students experiencing no change in their expansion of perception.

Question 10 did demonstrate weak saturation, with 58% (n=17) students coming into the class observing aesthetics in their daily lives at some level. At the end of the course this population improved, with 79% (n=23) students reporting this behavior.

Student responses to Question 11, “How important are aesthetics to your studies?” are shown below in Figure 1. It was found through a Wilcoxon-Signed rank test that there was no significant change pre to post in student responses to Question 11, or that it was unlikely that students report aesthetics as more important to their academic careers after taking AesDes.

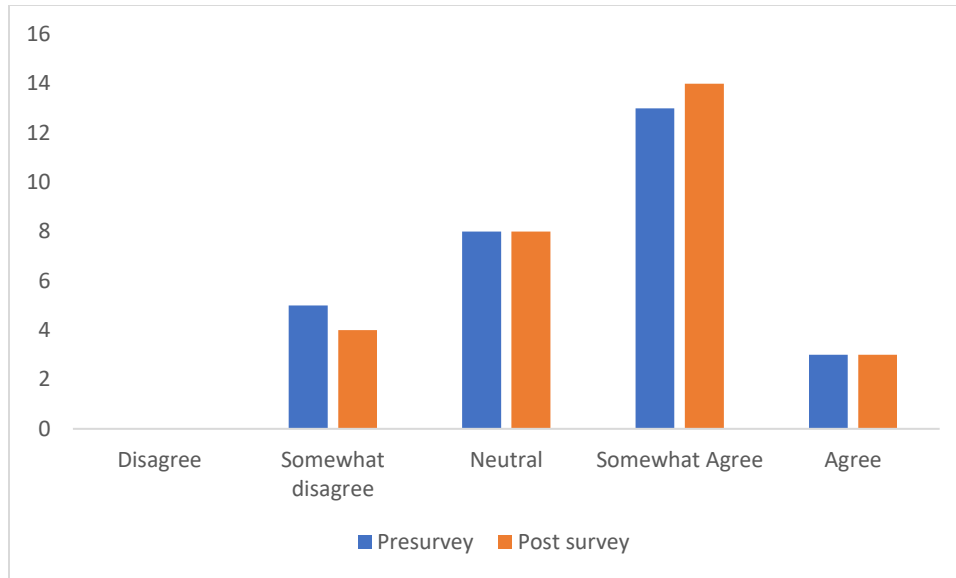


Figure 1: Student responses to Question 11 “How important are aesthetics to your studies?” of the AesDes survey. Wilcoxon Signed Rank test gave $P > .05$

Motivated Use

Motivated use was measured using Questions 7 and 12, as shown in Table 1.

From coding Question 7 it was found that 25% ($n=7$) of the students in the course experienced a gain in motivated use. These students discussed considering how the aesthetic they chose might affect the user of their projects or how the aesthetics they chose had a special meaning to them. Provided below are some student responses.

Pre survey	Post survey
“I mostly focus on what will be the most functional aesthetic.” (Subject 18)	“I am motivated by the audience of my design. If it is an industrial pipe, it's going to be function over form. However, if it is a product that people have to use, then I want it to look appropriately appealing.” (Subject 18)
“Functionally for the most part dictates what my design looks like.” (Subject 21)	“I chose an aesthetic based on personal experiences. I liked to [choose] things that resonate with my past.” (Subject 21)
“An inspiration of some sort or what person will be using it.” (Subject 24)	“My background as well as the purpose of the design.” (Subject 29)

Table 4: In the table above are paired pre- and post-survey responses to Question 7

As may be expected, many of the other responses showed that there was either a negative shift or little change across the semester in student motivation. This being said, a majority of these students saw no shift. This was not a surprise, as the following excerpts (which are taken from the pre-

survey) show, many of the students in the course already came in applying aesthetics in their designs.

“I always start by filling the design space as thoroughly as possible and then move to design the aesthetics around it. I am a strong believer that beautiful aesthetics come primarily from well thought out engineering solutions.” (Subject 25)

“It is not only physically appealing but mentally appealing when you design something that is both functional but aesthetically appealing.” (Subject 13)

“When designing something I choose from surrounding environments, cultures, and peoples interests.” (Subject 8)

The second question that was analyzed was Question 12. Student response data for Question 12 is presented in Appendix D. In this question students were given a list of reasons for them to choose to enroll in AesDes. Students could rank each reason from having no influence on their motivations to being major influences. After collecting student responses, these motivations were categorized as either internal or external motivations to determine if students were more motivated by internal factors, such as appreciation for aesthetics, or other external factors, like earning a good grade in the course. From the data it was found that students began to lose motivation across the semester, with student responses being driven towards neutral.

Affective Value

Affective value was measured using Questions 5, 8, and 12 as shown in Table 1.

Responses to Question 5 are shown in Figure 2 on the next page.

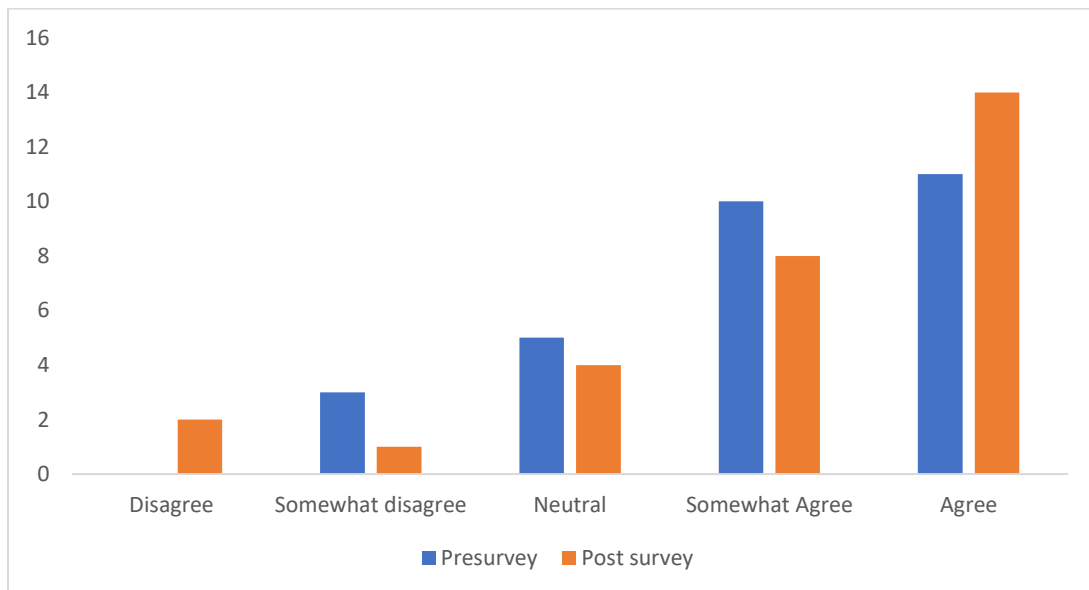


Figure 2: Student pre/post responses to Question 5 of the AesDes survey: Rate your agreement with the following statement: I am interested in a career that is predominantly focused on design.

Student responses to this question demonstrated a polarization of student interest in design focused careers, as shown in the chart above. However, a Two Sample F-test for variances showed that any

shifts in the variance of the data were insignificant. A Wilcoxon Signed Rank test of this data demonstrated the net change in student interest was not statistically significant.

To analyze Question 8 a coding scheme was developed. Through this scheme it was found that 25% of student responses indicated gain in affective value towards the project initiation stage. Examples of such responses can be found in Table 5.

Pre-Survey	Post-Survey
Gain Across Responses	
Overwhelmed because there are a lot of unknowns that lie ahead and it can be hard to wrap my brain around a starting point. (Subject 11)	A bit overwhelmed as I am unsure what direction my thing will go as there are many unknowns. but also excited for the same reason (Subject 11)
It makes me feel more empowered because I do not have to run things by a committee in order to get things done. It may limit my capabilities in terms of scale, but it allows me to see a vision through to the end without having to dilute it with the opinion of others. (Subject 1)	Making things on my own is always the most personally rewarding because it can be exactly the kind of vision that you have for it. There is no committee or negotiation with opposing viewpoints, but rather a more pure expression of the deepest opinions and qualities of the mind. (Subject 1)
Loss Across Responses	
Anxious and Excited. I have never really worked by myself to design something unique, so I'm excited to get started, but also not having other people's input on the design is going to make selecting one specific design quite tough. (Subject 12)	[S]lightly stressed out since there aren't other people to bounce ideas off in the ideation phase. It's tough to sometimes accept the fact that your design is not going to work and usually someone else needs to say that to you. (Subject 12)
Making things on my own is exciting at the beginning because there are a lot of possibilities for what I am creating. (Subject 9)	It is often difficult. The main reason is it is sometimes overwhelming to find all of the resources necessary. (Subject 9)

Table 5: Matched student responses to Question 8. Pre survey student responses are listed in the first column, with their post survey response listed in the second column. Question 8 asked: "How does making things on your own make you feel at the beginning of the process? Why does it make you feel that way?"

The final measure of affective value was Question 12, which focused on student motivation for enrolling in the class. It was found that upon comparing the pre/post responses that at the end of the semester there was a shift away from internal motivations to the external factors. In other words, by the end of the semester students were less motivated by an appreciation for aesthetics but rather by more material rewards from the course. This result was supported by comparing the average response to the factors that were considered intrinsic versus those that were considered extrinsic. The results were then compared using a Wilcoxon-signed rank test, which concluded that there was a significant shift across responses for both intrinsic and extrinsic motivations with $p < 0.01$.

A necessary consideration for Question 12 was socially desirable response bias, or the tendency of students to provide responses that they considered to be preferable to the researchers. This was particularly important for Question 12.5 “I expect this class to be less difficult than my other classes”. To test against this Question 13 was included, where students were asked how much time they expected to spend (pre) and actually did spend (post) on AesDes outside of class each week. Responses are shown in Figure 3.

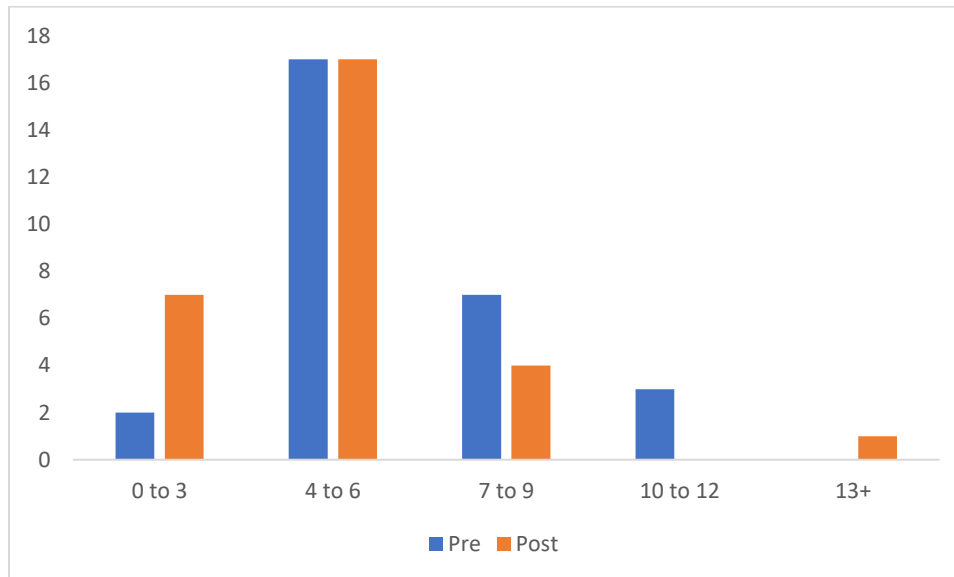


Figure 3: Above are the student pre and post survey responses to Question 13: “how much time do you expect to/ did you spend on this class each week?” Students provided responses in terms of hours.

It was found that there was little correlation between Questions 13 and 12_5, on the pre- ($r = -.299$) and post-survey ($-.251$). This means that there was low consistency between the two questions on both the pre- and post- survey; students expecting a difficult course did *not* also report expecting to spend a lot of time. An explanation for this result is students enrolled in AesDes expecting a low work load (low scores on expected time outside of class), but did not want to openly admit it when directly asked. It is also possible that there is no causal relationship between the two questions.

Engineering Identity

Disciplinary Knowledge

Disciplinary knowledge was measured by the four questions shown in Table 1, taken verbatim from the APPLES survey [7].

The first two of these questions were analyzed together. In both questions students were given the following list of skills: self-confidence (social), leadership ability, public speaking ability, math ability, science ability, communication skills, ability to apply math and science principles in solving real world problems, business ability, ability to perform in teams. Question 1 asked students “Rate yourself on each of the following traits as compared to your peers. We want the most accurate estimate of how you see yourself.” and Question 2 asked “How important do you think each of the following skills and abilities is to become a successful engineer?” By normalizing student responses to Question 1 (c_i) and scaling them based on their responses to Question 2 (w_i)

a score for each student was calculated which represented the student's average confidence in their skills as an engineer. This coefficient was calculated using the formula:

$$C_R = \frac{\sum_{i=0}^N c_i w_i}{\sum_{i=0}^N w_i}$$

Below are histograms of student responses. A score of -1 corresponds with a student who believes that they are not skilled as an engineer, while a 1 represents a strong belief in one's engineering ability.

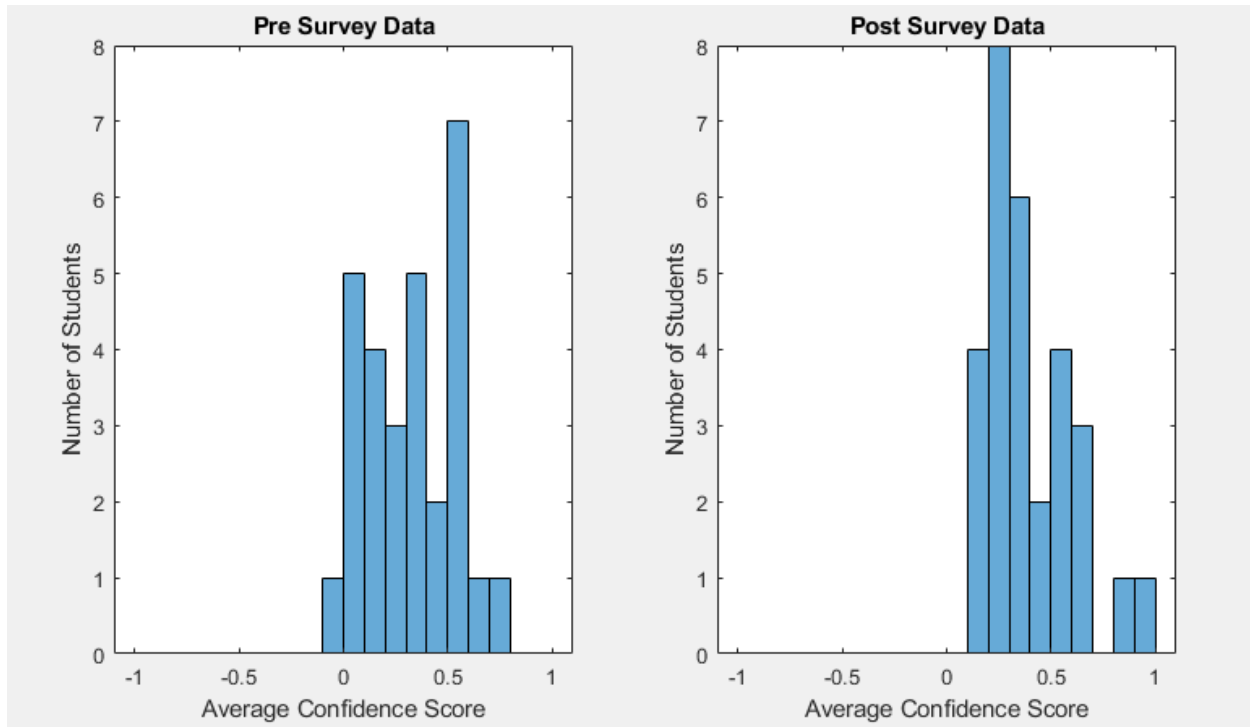


Figure 4: pre- and post-survey data of student engineering confidence.

After tabulating the confidence score for each student, it was found that there was a 23% shift across responses which was statistically significant. *In other words, after the course students found that their skillset more closely resembled that what they thought a professional engineer should have.*

The second question that mapped to disciplinary knowledge was Question 3. Question 3 was identical to Question 1 except the list of skills was different. The new list was creativity, aesthetic design, functional design, drawing ability, manufacturing skills, critiquing ability, ideation ability, appreciation for aesthetics, ability to identify major design movements. For each of these questions a Wilcoxon signed rank test was performed to detect shifts in student confidence. The results are shown in Table 6

Only three of the aesthetic skills had a significant change through the AesDes class. It was found that the students in AesDes experienced a loss in their confidence in their creativity and a gain in confidence when using manufacturing skills or doing functional design work. A possible explanation for the loss in creativity is the Dunning-Kruger effect. The Dunning-Kruger effect is

an individual’s tendency to become less confident in their knowledge and skills surrounding a certain topic as they learn more about it [10]. It was found that students ended AesDes feeling more confident in both functional design and manufacturing skills, which is indicative of an increase in their engineering identity

Engineering skill	P-value	Gain or loss
Question 3.1 - Creativity	<0.01	Loss
Question 3.2 - Aesthetic design	N/A	N/A
Question 3.3 - Functional design	<0.01	Gain
Question 3.4 - Drawing ability	N/A	N/A
Question 3.5 - Manufacturing skills	<0.01	Gain
Question 3.6 -Critiquing ability	N/A	N/A
Question 3.7 - Ideation ability	N/A	N/A
Question 3.8 - Appreciation for aesthetics	N/A	N/A
Question 3.9 - Ability to identify major design movements	N/A	N/A

Table 6: Results to Question 3 on AesDes survey. Question 3 asked, “Rate yourself on each of the following traits as compared to your peers in your classes. We want the most accurate estimate of how you see yourself.” The P-value corresponds to the p value provided by the Wilcoxon signed rank test to determine if there was a significant change across pre/post survey responses.

The final question that was analyzed was Question 4. Student responses are shown in Figure 5.

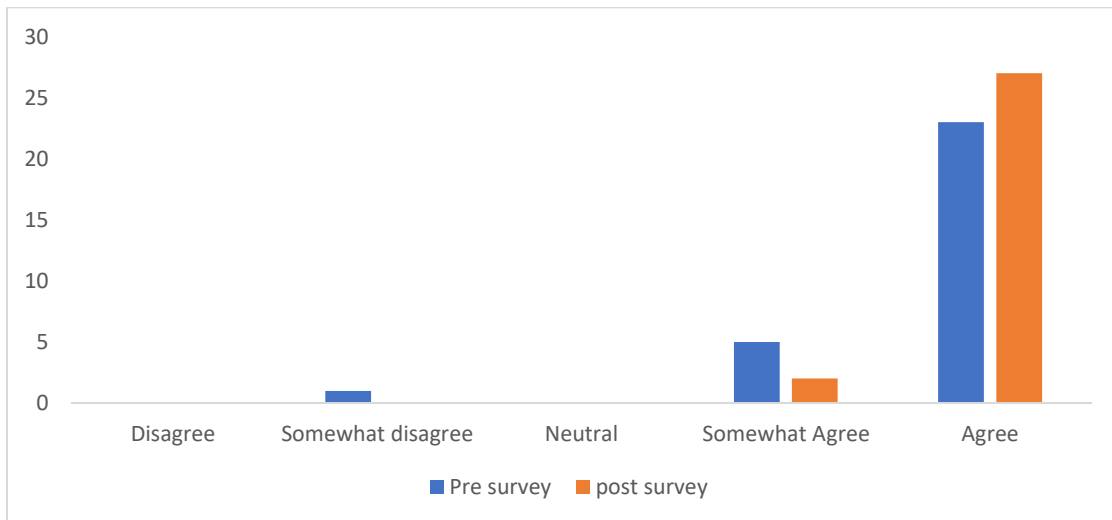


Figure 5: Student responses to Question 4 of the AesDes survey. Question 4 asked, “The final for this course is to complete an aesthetics-based design project. Rate your agreement with the following statement: I am confident in my ability to succeed on such a project.”

Upon comparing responses, it was found that any shift was not statistically significant. It was clear on this question that the survey was saturated. Almost the entire class answered the highest level of agreement, a 5, on their confidence on the pre survey when it came to making the AesDes project, leaving no room to detect growth.

Identification and Navigation

The second and third indicators of engineering identity are navigation and identification. Navigation was measured by Questions 6 and 16 while identification was measured by three sub questions on Question 16. Questions 6 and 16 are outlined in Table 7.

Question Number	Question text	Question Format
Question 6	Rate your agreement with the following statement: I believe that I am capable of successfully pursuing a career that is predominantly focused on design.	Multi-item 5-point Likert scale
Question 16	What influenced your decision to enroll in this course?	Multi-item 5-point Likert scale

Table 7: Navigation was measured using Questions 6 and 16 on the AesDes survey. All sub items of Question 16 can be seen in Appendix A.

Student response Data to Question 6 is shown in Figure 6.

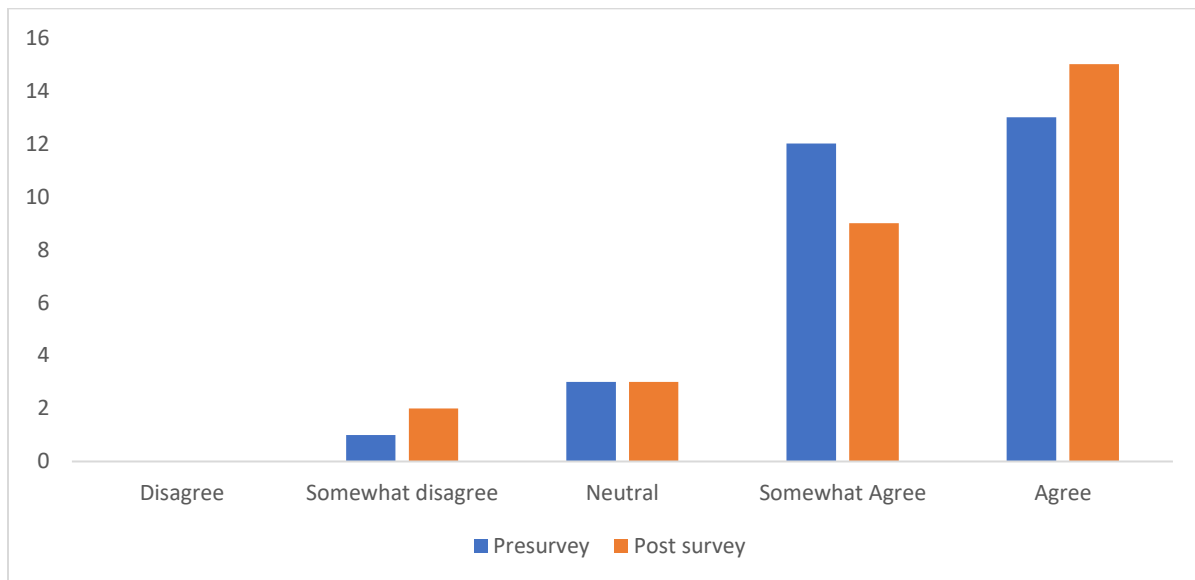


Figure 6: Student responses to Question 6 on the AesDes survey. Question 6 asks, "Your agreement with the following statement: I believe that I am capable of successfully pursuing a career that is predominantly focused on design."

It is apparent that there was no significant shift ($p >> .05$) across responses. Again, this question demonstrates saturation in the student population.

The final question that was scored was Question 16 which asks why a student chose to study engineering. In this question, students are given 16 statements and asked to rate each on how much

of an influence it plays in their decision to study engineering. Listed in Table 4 are the 16 statements students were given. Each of these statements has been sorted to match with other statements with similar meanings; they were not presented in this order (see Appendix A).

Question 16
Social Good
Technology plays an important role in solving society’s problems
Engineers have contributed greatly to fixing problems in the world
Engineering skills can be used for the good of society
Financial
Engineers make more money than most other professionals
Engineers are well paid
An engineering degree will guarantee me a job when I graduate
Parental Influence
My parent(s) would disapprove if I chose a major other than engineering
My parent(s) want me to be an engineer
Intrinsic Psychological
I feel good when I am doing engineering
I think engineering is fun
I think engineering is interesting
Intrinsic Behavioral
I like to build stuff
I like to figure out how things work
Mentor Influence
A faculty member, academic advisor, teaching assistant or other university affiliated person has encouraged and/or inspired me to study engineering
A non-university affiliated mentor has encouraged and/or inspired me to study engineering
A mentor has introduced me to people and opportunities in engineering

Table 8: Question 16 statements related to Engineering Identity, grouped by interest area. This question came from the APPLES survey [7].

Using these statements, identification was measured using the mentor and parental influence statements, while navigation was measured using the remaining categories. This allowed for the construction of a metric of why students were in engineering. After comparing pre/post responses the following changes were found in student motivation.

Question	P-value	Gain or loss
Social Good	N/A	N/A
Financial	0.05	Gain
Parental Influence	0.01	Gain
Mentor influence	N/A	N/A
Intrinsic Psychological	N/A	N/A
Intrinsic Behavioral	N/A	N/A

Table 9: Significance levels of shifts in Question 16. Question 16 asks: “We are interested in knowing why you are studying engineering. Please indicate below the extent to which the following reasons apply to you”. The P-value corresponds to the p-value provided by the Wilcoxon signed rank test to determine if there was a significant change across pre/post survey responses.

From Table 9 it can be gathered that the only motivational shifts that the AesDes students experienced was in terms of financial motivation and parental influence. This would be indicative of students perceiving an increase in the importance of their parents' opinions of their profession and financial incentives. Therefore, there is currently no evidence to indicate that students are experiencing a gain in identification.

Testing against external factors

In the previous iteration of the AesDes survey, administered in the 2020 spring semester, it was found that many of the students in the class experienced a large gain in engineering identity at the end of the semester, shifting from identifying themselves as engineering students to real-life engineers. Coding of the 2020 survey showed that many students who experienced this gain also graduated at the end of that semester. A concern was raised that students are experiencing a gain in engineering identity not because of AesDes but because they received a large external identification from the university at the end of the semester. It was found that since students were given a college diploma in engineering at the end of the semester students were receiving a large form of external validation in their engineering skills, which was manifesting in the AesDes survey. To check shifts in engineering identity in this study the AesDes student responses were broken into two groups, students who were enrolled in the mechanical engineering senior design course at the same university (n=21), and students who were not (n=8). Each of these groups were then analyzed separately and compared to determine if there were any shifts in identity that were independent of senior design.

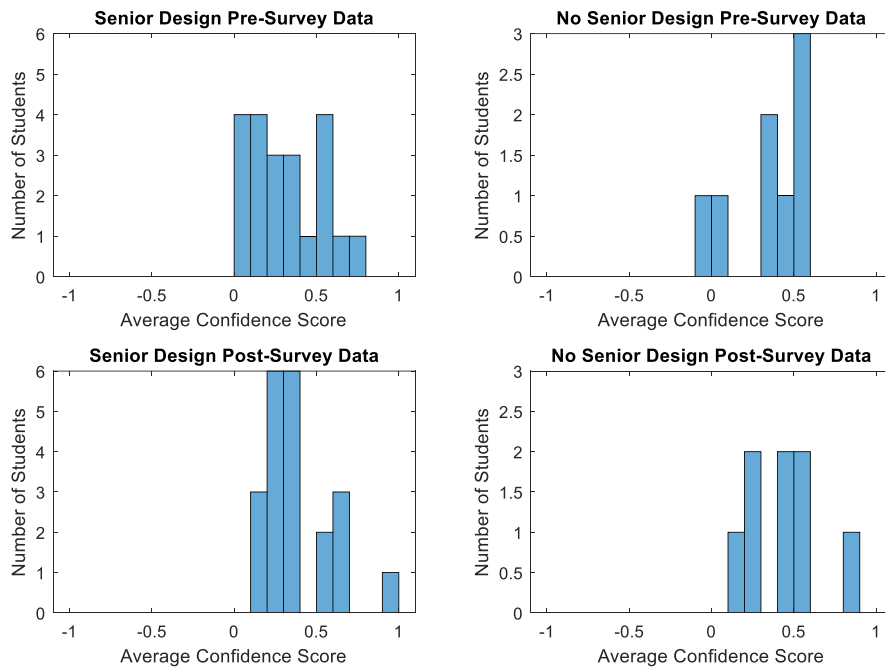


Figure 1: Confidence Scores for sorted AesDes groups. Students were grouped by students who were concurrently enrolled in both senior design and AesDes and those who were not.

The main indicator that was examined was disciplinary knowledge. It was found that for questions 1 and 2, when tested separately, neither group experienced a significance shift in confidence. A similar result was found for Questions 3, as demonstrated by the table below.

Question	No Senior Design		Senior Design	
	W-Statistic	P-value	W-Statistic	P-value
Creativity	5	N/A	24	N/A
Aesthetic design	7.5	N/A	18	N/A
Functional design	1.5	N/A	8	N/A
Drawing ability	0	N/A	35	N/A
Manufacturing skills	1.5	N/A	8	N/A
Critiquing ability	10	N/A	25	N/A
Ideation ability	0	N/A	25	N/A
Appreciation for aesthetics	6	N/A	46	N/A
Ability to identify major design movements	3	N/A	41.5	N/A

Table10: Table demonstrating student confidence in aesthetic skills.

It was found that again, individually, neither group of the students within AesDes during Spring 2021 experienced any significant change in confidence. Finally for Question 4, which was fully saturated in the ‘strongly agree’ category, it was found that there was no significant change for either group of the students in AesDes. We speculate that the lack of gain in identity in Spring 2021 when contrasted with Spring 2020 may be pandemic related, however no conclusions can be drawn due to the saturation in the data.

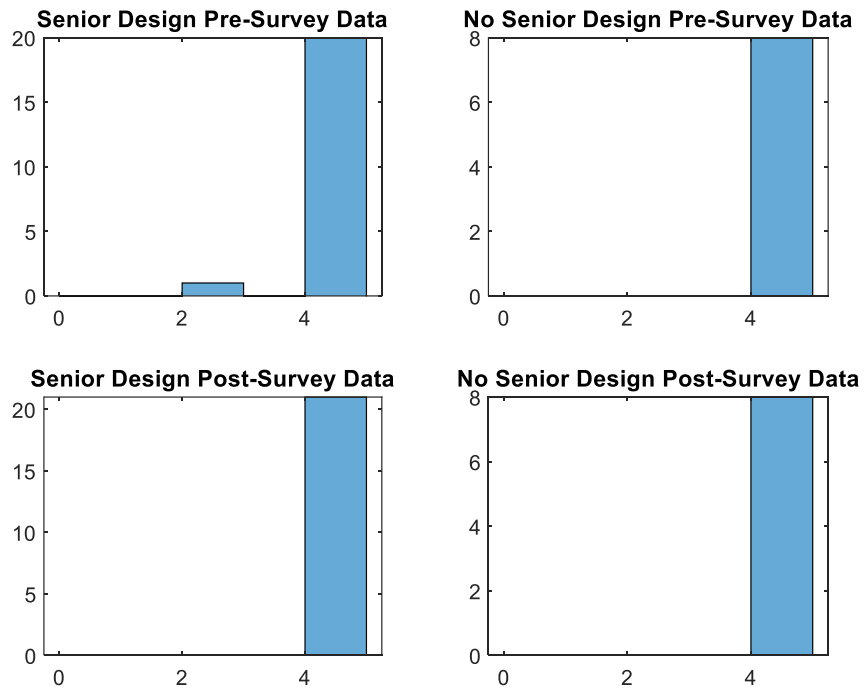


Figure 2: Student response to Question 4 when separated by senior design enrollment.

Emergent Results

When it came to the three indicators of the transformative experience it was found that the students who came in to AesDes did not leave feeling more or less excited about aesthetics nor were they choosing to apply aesthetics in their lives more than they previously were. The gain that had a significant gain among students was expansion of perception. While this gain is a good first step it is not the full transformative experience as was suggested by surveys in previous semesters. A likely contributing factor is that this study was done during an online offering of the course during the second year of the COVID-19 pandemic. Students were facing burnout from online classes and other social factors. This factor was mentioned in some student responses. A final consideration is that all of the students who enroll in AesDes are upper division engineering students who have had an opportunity to develop a passion for engineering. It is possible that these students are experiencing only small shifts because of this and AesDes could have a more significant effect on lower division students.

Pre-Survey	Post-survey
Question 8	How does making things on your own make you feel at the beginning of the process? Why does it make you feel that way?
Making things on my own is exciting at the beginning because there are a lot of possibilities for what I am creating. (Subject 9)	It is often difficult. The main reason is it is sometimes overwhelming to find all of the resources necessary. (Subject 9)
Question 9	Are aesthetics important to the career you intend to pursue after graduation? Explain. Feel free to include what career you are interested in.
[Aesthetics] are slightly important to my career - I will likely start my career as a design engineer for a medical device company that I've been working for the past three years. Knowing how to design more aesthetically pleasing parts is something that I personally want to strive for - it may not be the most critical aspect of my first job, but that's where hobbies come in. (Subject 19)	Not really (Subject 19)
Yes, I am very interested in the junction between aesthetics and functionality. Right now I work for a furniture shop that primarily makes custom pieces for clients, and I think it would be very difficult for me to quit and work in an office. (Subject 7)	I will continue working at a local custom furniture shop, so yes. (Subject 7)

Table 11: Above are student responses to questions 8 and 9 on the post-survey.

In their response to Question 8 Student 9 expresses at the end of the semester that when making something on their own and at home they feel stressed out because they must locate resources. Because of COVID-19 the students in AesDes were not able to access the university makerspaces

and resources that would normally have been available to the students. Obviously, for a student who would rely on these spaces in a normal semester it could create a lot of stress to need to find a way to mill a piece for their project, for example. This effect became more apparent when the length of student open responses was considered.

Question #	Average post-survey response word count	Average post-survey response word count	P- value
7	25.8	21.6	.11
8	39.3	24.4	>>.01
9	39.2	29.3	.01
10	36.2	23.6	>>.01

Figure 12: Average word counts for student responses to open response questions on AesDes survey. P-values are reported for student t-tests of the data.

Student response lengths were compared pre- and post-surveys. It was found that after the first free response question students response lengths dropped by one standard deviation. While this may be a pandemic related result, a retrospective analysis of free response survey questions comparing pre and post response lengths would be interesting. This is a question for future research.

Discussion

Transformative Experience

In measuring the transformative experience, it was found that the AesDes students experienced positive gains in motivated use and expansion of perception, but no change was shown in affective value. This was evidenced by the 25% of students who experienced a gain in motivated use and the 40% of students who expressed observing aesthetics more often in their daily lives. These results suggest that that while the students who take AesDes are experiencing a cognitive gain and they see their learning in their daily lives, they still need help finding joy or fulfillment in their learning. One explanation for this lack of affective gain in the AesDes students is that many of the students who took AesDes were already interested in the common ground between art and engineering, and we were not able to measure a further gain in affective value.

Engineering Identity

It was found that 23% of the students in AesDes experienced a gain towards their confidence in their engineering skills, particularly those relating to manufacturing and functional design. While students did experience this cognitive gain, students continued to struggle to demonstrate change in their identification or navigation as engineers as they began to value external motivators such as money and parental approval more.

Emergent Results

On another note, it was noticed by the research team that in comparing the pre- and post- data the length of student responses seemed to drop off. This observation was quantified by the comparison in word counts across responses, where it was found that on the last three of the four free response questions of the AesDes survey response lengths dropped by one standard deviation. This drop could be a result of the shift to remote learning due to COVID-19 or student survey fatigue. Another possible explanation could be that as the semester progressed students

began to lose interest in the topics discussed in the course (experienced an affective loss) and as a result were less motivated to discuss their learning on the post survey.

Conclusion

Findings

At the University of Colorado at Boulder a new type of engineering class has been developed, one that focuses on the value of aesthetics as a tool to inspire engineering achievement instead of the traditional requirements-based approach. The most recent of these courses, AesDes, is producing students who notice aesthetics in their day-to-day lives and feel more confident as engineers. As demonstrated by the validated AesDes survey, the students who enter AesDes leave the course with gains in confidence in their engineering skills and expansion of perception.

Lessons Learned

Through this project it has been discovered that aesthetics provides students with an enjoyable and widely relevant learning experience, even during pandemic conditions. However, many students enter the classroom already excited about course content and aesthetics. Because of this, future iterations of the AesDes survey that choose to measure students and their relationship with aesthetics may need to provide more context as to what is meant by aesthetics. Another possible improvement for the AesDes survey will be to reword the questions where students had issues with interpretation, replacing terms such as “self-confidence (social)” and “ideation” with terms that are more common in student vernacular. Additionally, because AesDes is an elective course, future investigations of the AesDes course will benefit from an adequate control group to better understand the students within the classroom and isolate the impact of the course.

Next Steps

Moving forward there are several possible next steps from this study. One possibility would be to take the AesDes survey and develop a more generalized version that can be used to measure the transformative experience in any engineering course. Perhaps a more interesting question is where an intervention like AesDes would be most impactful in an undergraduate engineering curriculum. As it stands now, AesDes is only available to upper-division and graduate level students, while lower division students do not have much incentive to enroll. By investigating where in an engineering curriculum students feel least like an engineer or suffer the largest affective loss it would be possible to determine where aesthetics-based course work can serve to bolster student affect and sense of belonging. A final question that remains is to continue to investigate what factors influence student response length and its relation to student affect. If there is a strong correlation between the two, the detail to which students respond to free response questions could be used as a metric for determining the affective value students perceive towards a given topic.

Acknowledgements

We would like to acknowledge the University of Colorado AI-EER Interdisciplinary Research Theme and the Discovery Learning Apprenticeship (DLA) program and Sharon E. Anderson, Director of Active Learning for their funding contribution to the project.

Appendix A: AesDes Survey Text

Question Number	Question statement
1	Rate yourself on each of the following traits as compared to your peers. We want the most accurate estimate of how you see yourself*
1.1	Self-confidence (social)
1.2	Leadership ability
1.3	Public Speaking ability
1.4	Math ability
1.5	Science ability
1.6	Communication Skills
1.7	Ability to apply math and science principles in solving real world problems
1.8	Business ability
1.9	Ability to perform in teams
2	How important do you think each of the following skills and abilities is to becoming a successful engineer?*
2.1	Self-confidence (social)
2.2	Leadership ability
2.3	Public Speaking ability
2.4	Math ability
2.5	Science ability
2.6	Communication Skills
2.7	Ability to apply math and science principles in solving real world problems
2.8	Business ability
2.9	Ability to perform in teams
3	Rate yourself on each of the following traits as compared to your peers in your classes. We want the most accurate estimate of how you see yourself.
3.1	Creativity
3.2	Aesthetic design
3.3	Functional design
3.4	Drawing ability
3.5	Manufacturing skills
3.6	Critiquing ability
3.7	Ideation ability
3.8	Appreciation for aesthetics
3.9	Ability to identify major design movements
4	The final for this course is to complete an aesthetics-based design project. Rate your agreement with the following statement: I am confident in my ability to succeed on such a project.
5	Rate your agreement with the following statement: I am interested in a career that is predominantly focused on design.

6	Rate your agreement with the following statement: I believe that I am capable of successfully pursuing a career that is predominantly focused on design.
7	What motivates you when choosing an aesthetic while designing something?
8	How does making things on your own make you feel at the beginning of the process? Why does it make you feel that way?
9	Are aesthetics important to the career you intend to pursue after graduation? Explain. Feel free to include what career you are interested in.
10	Are aesthetics important in your non-professional life? Explain.
11	How important are aesthetics to your studies?
12	What influenced your decision to enroll in this course?
12.1	This is a class about making/building things
12.2	I want to learn about industrial design
12.3	I want to learn to make attractive designs
12.4	This is the only course including art I could take for my degree
12.5	I expect this class to be less difficult than my other classes
12.6	I need an elective to fit my schedule
12.7	I want a course that allows creativity
12.8	I want to take as much design as I can
12.9	This course looks like fun
12.10	I want to take a class taught by Professor Hertzberg
12.11	I think this class will help me build my resume
12.12	Other
13	How much time do you expect to spend working on AesDes each week outside of class?
14	What is your major? Select all that apply.
15	We are interested in knowing why you are studying engineering. Please indicate below the extent to which the following reasons apply to you:*
15.1	Technology plays an important role in solving society's problems
15.2	Engineers make more money than most other professionals
15.3	My parent(s) would disapprove if I chose a major other than engineering.
15.4	Engineers have contributed greatly to fixing problems in the world
15.5	Engineers are well paid
15.6	My parent(s) want me to be an engineer
15.7	An engineering degree will guarantee me a job when I graduate
15.8	A faculty member, academic advisor, teaching assistant or other university affiliated person has encouraged and/or inspired me to study engineering
15.9	A non – university affiliated mentor has encouraged and or inspired me to study engineering
15.10	A mentor has introduced me to people and opportunities in engineering
15.11	I feel good when I am doing engineering
15.12	I like to build stuff
15.13	I think engineering is fun
15.14	Engineering skills can be used for the good of society
15.15	I think engineering is interesting

15.16

I like to figure out how things work

**Question from APPLES [7]*

Appendix B: Coding Scheme

Provided below is a detailed coding scheme for each of the six major constructs in this study: Affective Value, Motivated Use, Expansion of Perception, Disciplinary Knowledge, Identification, Navigation. Although each open response question was designed to measure one specific construct each, each open response question was coded for all 6 constructs. In the analysis for this study, coding was used to determine shifts in each of the constructs across student pre and post responses. To do this, pre and post responses were first coded separately, then codes were compared across the responses to determine if there had been any change. This method allowed for both a net shift across the semester (comparison of responses) and an overall trend (individual codes) in student responses to be measured. Due to none of the open response questions being designed to measure engineering identity it was rare for codes to indicate shifts in Disciplinary Knowledge, Identification, and Navigation.

Affective Value

In order for a response to be tagged with a shift in affective value the student needed to provide an emotional response about a topic relating to those discussed in AesDes, this meant that student responses proving a positive feeling towards aesthetics or design would be flagged as experiencing a positive shift in affect.

Positive Affective Value	No Affective Value	Negative Affective Value
<p>“Aesthetics are very important in my non-professional life. I build furniture for fun and enjoy just drawing furniture that I may never build. I take inspiration from all the design aesthetics around me all the time. I am generally most drawn to mid-century modern, industrial, or "farm" aesthetic furniture for my own designs. “ (Subject 15)</p>	<p>“I like things to look nice in my house and other things that I own. I wouldn't say that they are so important that they run my life.” (Subject 21)</p>	<p>“No, I'm a pretty plain Jane. My walls are bare and I have no non-functional decorations besides my American flag. “ (Subject 18)</p>

Table 4: above are student responses to question 10 of the Pre-survey. As can be seen, each of the examples provides a situation where a student response was coded as having positive, neutral, and negative affect respectively.

Motivated Use

A response was coded as relating to motivated use if a student expressed a desire (or lack thereof) to use aesthetics and design in their work or daily lives. Additionally, if a student expressed that they felt that their learning could be applied, their response was tagged for motivated use.

Positive Motivated Use	Neutral Motivated Use	Negative Motivated Use
<p>“Well, I'm going into aerospace so it's definitely not super important, but it could have an impact on like selling an idea to a client. “ (Subject 3)</p>	<p>“Not necessarily I am an AFROTC cadet and will be flying for the Air Force. I would say though that many planes are designed with aesthetics in mind”</p>	<p>“Aesthetics are not important at all to the job I will be having after graduation. I will be operating nuclear reactors for the Navy and those haven't had any design changes in decades</p>

	(Subject 25)	and are designed entirely for functionality.” (Subject 4)
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Table 5: Student responses to Question 9. These responses were taken from the pre- and post-survey. As can be seen, each of the examples provides a situation where a student response was coded as having positive, neutral, and negative affect respectively.

Expansion of Perception

A response was tagged as Expansion of Perception if the student expressed seeing aesthetics in their daily life. Students who expressed that aesthetics were generally unimportant were tagged as negative expansion of perception.

Positive Expansion of Perception	Neutral Expansion of Perception	Negative Expansion of Perception
Yes. Obviously, aesthetics come into play in basically any materialistic item, and usually, aesthetics is the top, if not one of the top factors that lead to choosing one item over another. (Subject 12)	Yes again the human brain loves aesthetic things. (Subject 13)	There aren't too important in my non-professional life, I am more concerned with functionality. (Subject 4)

Table 6: Student responses to Question 10. These responses were taken from the pre-survey. As can be seen, each of the examples provides a situation where a student response was coded as having positive, neutral, and negative affect respectively.

Disciplinary Knowledge

A response was tagged for Disciplinary Knowledge if the student discussed their perception of their learning. Very few students discussed Disciplinary Knowledge in their open responses, and no neutral Disciplinary Knowledge code was found.

<i>Positive Disciplinary Knowledge</i>	<i>Neutral Disciplinary Knowledge</i>	<i>Negative Disciplinary Knowledge</i>
“When I design something, I try to choose an aesthetic that suits the function of whatever I am designing. A lot of the time, materials used in engineering projects are dictated by the function of the product, but that doesn't mean they can't look good as well. Choosing the finish can a part look much better. I also try to make functional improvements that also improve aesthetics, such as removing weight from a metal part by cutting patterns out of it.” (Subject 14)	N/A	“It makes me feel free because I can choose whatever route I want and can make decisions on my own. I also feel nervous because I have nobody to double-check my work.” (Subject 26)

Table 7: Student responses to Questions 7 and 8 respectively. These responses were taken from the pre-survey. As can be seen, each of the examples provides a situation where a student response was coded as having positive, neutral, and negative affect respectively.

Identification

A response was tagged for identification if the student discussed either seeing themselves as an engineer, such as saying “I am an engineer” or if they mentioned someone else calling them an engineer. No students provided responses that were indicative of negative Identification.

Positive Identification	Neutral Identification	Negative Identification
“Yes, about 1 year ago I started an engineering design consultancy and I would love to be able to include more aesthetics into the design of products however, most of the time they are only interested in functionality.” (Subject 13)	“Aesthetics are certainly important to the career I intend to pursue after graduation. I am not sure exactly what I want to do yet, but I am looking to go into some sort of engineering design. I particularly enjoy product design because it allows me to be creative, and I find the design process to be very satisfying and fulfilling. I am particularly interested in vehicle design, for which aesthetics are very important, as this is a huge factor in the popularity and success of a vehicle.” (Subject 14)	N/A

Table 8: Student responses are taken from Question 9. These responses were taken from the post-survey. As can be seen, each of the examples provides a situation where a student response was coded as having positive, and neutral Identification.

Navigation

A response was tagged for navigation if it discussed how the student felt that they were doing things that engineers do, such as accepting a position as a full-time engineer after graduation. Responses were marked as having negative navigation only if not feeling like an engineer was expressly mentioned.

Positive Navigation	Neutral Navigation	Neutral Navigation
Yes. I'm currently working as a Systems Engineer at a medical device company and the aesthetic and design of the body of our device and user interfaces are very important for adoptability and usability. (Subject 22)	“Aesthetics could potentially be important in my future career. As of right now, I am looking into consulting and I really don't know how aesthetics could apply to this position.” (Subject 28)	“Let's be clear here, I'll take any job that pays after graduations. With that said, one of my interests is design. I would be happy to pursue a career in design after graduation, but feel that I may need more education before I can be competitive in the job search.” (Subject 15)

Table 9: Student responses to Question 9. These responses were taken from the pre- and post-survey. As can be seen, each of the examples provides a situation where a student response was coded as having positive, neutral, and negative affect respectively.

Provided below is a detailed coding scheme for each of the six major constructs in this study: Affective Value, Motivated Use, Expansion of Perception, Disciplinary Knowledge, Identification, Navigation. Although each open response question was designed to measure one specific construct each, each open response question was coded for all 6 constructs. In the analysis for this study, coding was used to determine shifts in each of the constructs across student pre and post responses. To do this, pre and post responses were first coded separately, then codes were compared across the responses to determine if there had been any change. This method allowed for both a net shift across the semester (comparison of responses) and an overall trend (individual codes) in student responses to be measured. Due to none of the open response questions being designed to measure engineering identity it was rare for codes to indicate shifts in Disciplinary Knowledge, Identification, and Navigation.

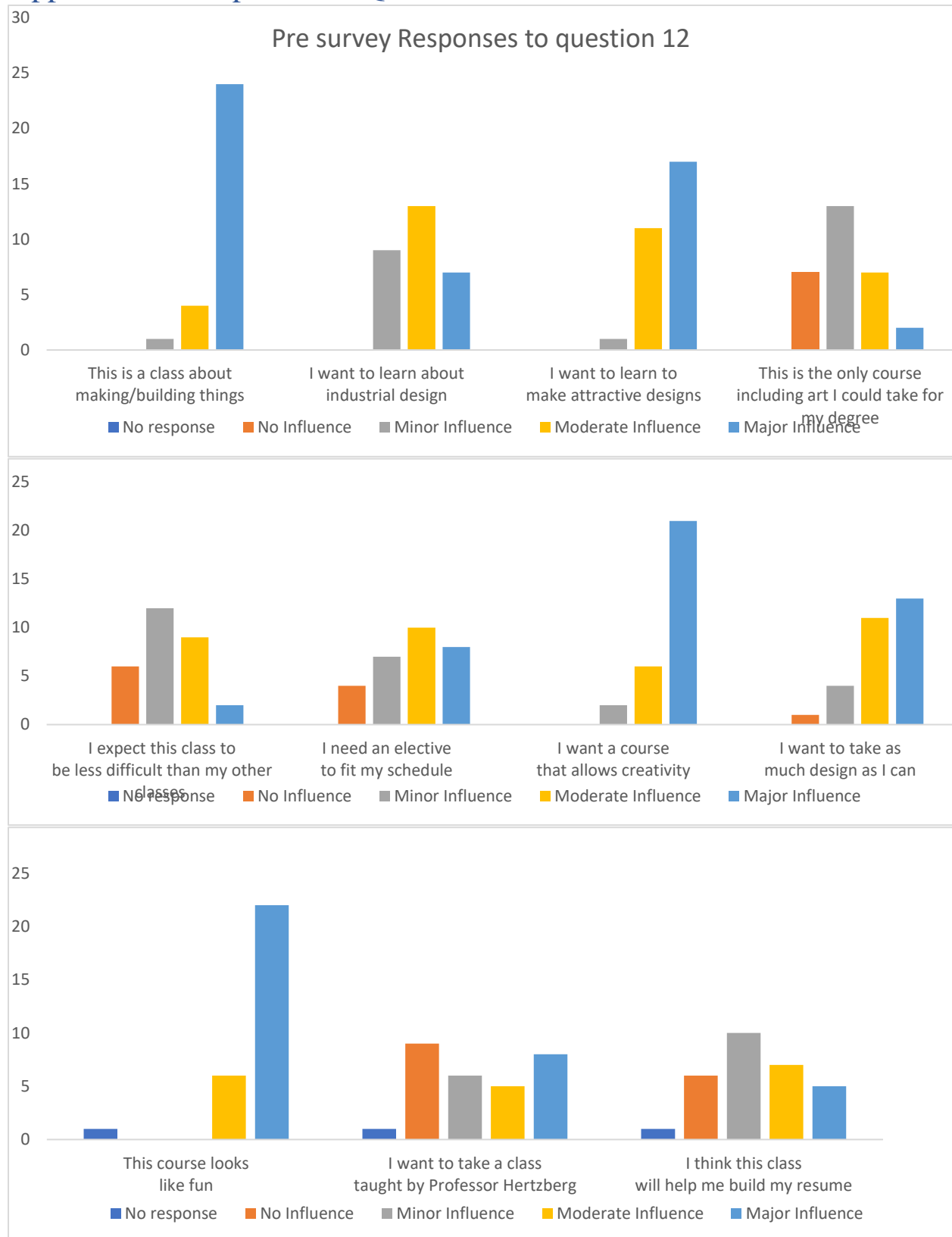
Appendix C: Comparison of Cronbach's α Between APPLES2 and AesDesPre

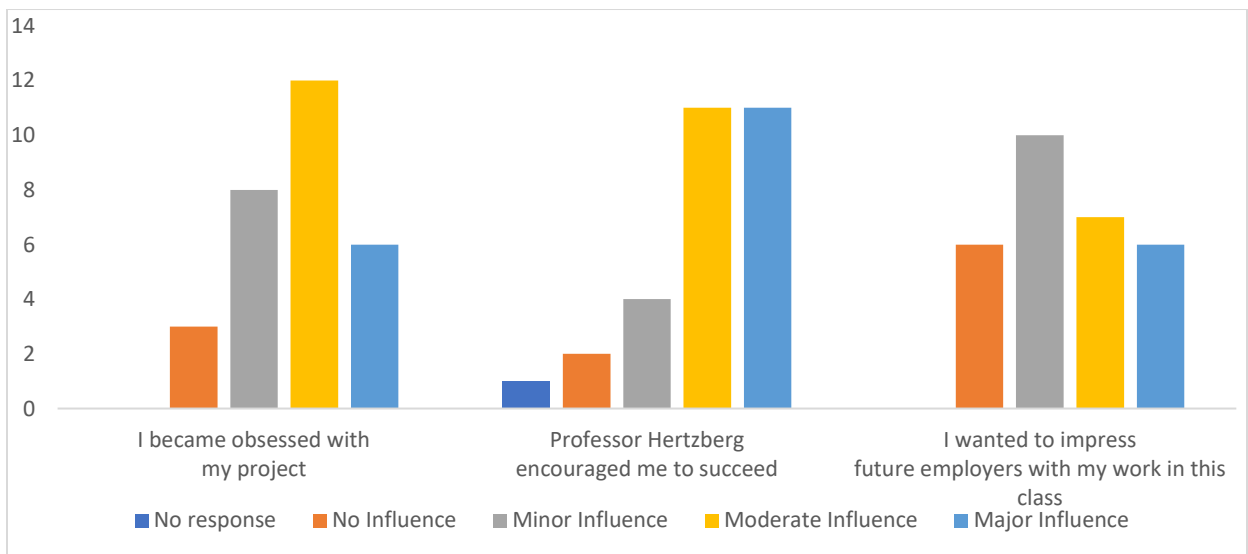
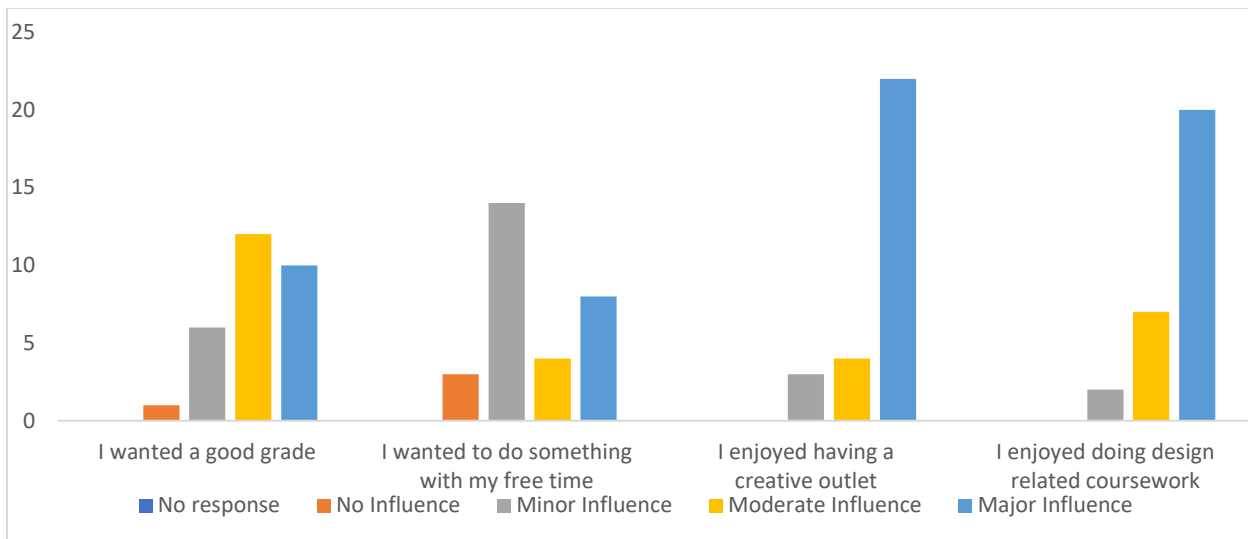
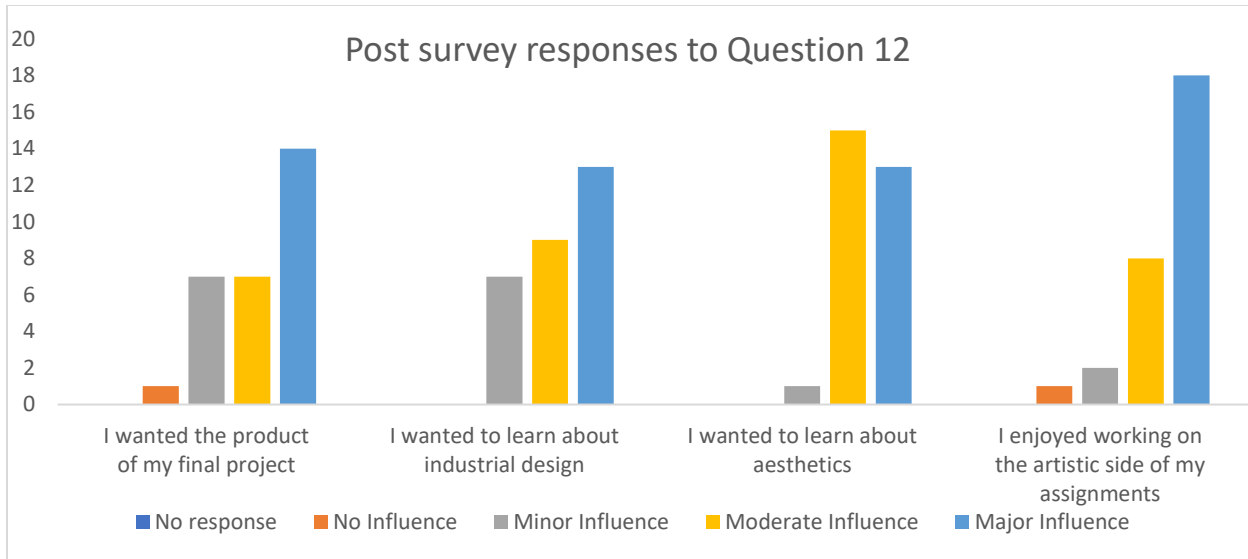
Question	APPLES2 Cronbach's α^*	AesDesPre Cronbach's α
Social Good	0.77	0.90
Question 15.1 - Technology plays an important role in solving society's problems.		
Question 15.4 - Engineers have contributed greatly to fixing problems in the world.		
Question 15.14 - Engineering skills can be used for the good of society.		
Financial	0.81	0.87
Question 15.2 - Engineers make more money than most other professionals.		
Question 15.5 - Engineers are well paid.		
Question 15.7 - An engineering degree will guarantee me a job when I graduate.		
Parental influence	0.83	0.96
Question 15.3 - My parent(s) would disapprove if I chose a major other than engineering.		
Question 15.6 - My parent(s) want me to be an engineer.		
Mentor Influence	0.77	0.63
Question 15.8 - A faculty member, academic advisor, teaching assistant or other university affiliated person has encouraged and/or inspired me to study engineering.		
Question 15.9 - A non-university affiliated mentor has encouraged and/or inspired me to study engineering.		
Question 15.10 - A mentor has introduced me to people and opportunities in engineering.		
A mentor has supported my decision to major in engineering		Not asked
Intrinsic Psychological	0.75	0.83
Question 15.11 - I feel good when I am doing engineering.		
Question 15.13 - I think engineering is fun.		
Question 15.15 - I think engineering is interesting.		
Intrinsic Behavioral	0.72	0.73
Question 15.12 - I like to build stuff.		
Question 15.16 - I like to figure out how things work.		
Confidence in Math and Science Skills	0.80	0.66
Question 1.5 - Confidence: Science ability		
Question 1.4 - Confidence: Math ability		
Question 1.7 - Confidence: Ability to apply math and science principles in solving real world problem		
Confidence in professional and Interpersonal Skills	0.82	0.69

Question 1.1 - Confidence: Self-confidence (social)		
Question 1.2 - Confidence: Leadership ability		
Question 1.3 - Confidence: Public speaking ability		
Question 1.6 - Confidence: Communication skills		
Question 1.8 - Confidence: Business ability		
Question 1.9 - Confidence: Ability to perform in teams		
Perceived Importance of Math and Science Skills	0.80	0.66
Question 2.4 - Perceived importance: Math ability		
Question 2.5 - Perceived importance: Science ability		
Question 2.7 - Perceived importance: Ability to apply math and science principles in solving real world problems		
Perceived Importance of Professional and Interpersonal Skills	0.82	0.79
Question 2.1 - Perceived importance: Self-confidence (social)		
Question 2.2 - Perceived importance: Leadership ability		
Question 2.3 - Perceived importance: Public speaking ability		
Question 2.6 - Perceived importance: Communication skills		
Question 2.8 - Perceived importance: Business ability		
Question 2.9 - Perceived importance: Ability to perform in teams		

Table 10: Comparison of original survey Cronbach's alpha to that of the revised version. Question numbers refer to how the question appeared on the AesDes survey. *(Sheppard et al.)

Appendix D: Responses to Question 12





References

- [1] C. Baillie and G. Fitzgerald, "Motivation and attrition in engineering students," *European Journal of Engineering Education*, vol. 25, no. 2, pp. 145–155, Jun. 2000, doi: 10.1080/030437900308544.
- [2] Goodman, Ewen, Hunter, Hertzberg, Jean, and Harriman, Jiffer, "Aesthetics of Design: a Case Study: American Society for Engineering Education," presented at the ASEE's 122nd Annual Conference and Exposition, Seattle, WA, United states, Jun. 2015. Accessed: Oct. 20, 2014. [Online]. Available: <http://www.asee.org/public/conferences/56/papers/12312>
- [3] K. Pugh, "Teaching for Idea-based, Transformative Experiences in Science: An Investigation of the Effectiveness of Two Instructional Elements," *The Teachers College Record*, vol. 104, no. 6, pp. 1101–1137, 2002.
- [4] K. A. Goodman, "THE TRANSFORMATIVE EXPERIENCE IN ENGINEERING EDUCATION," University of Colorado, Boulder, CO.
- [5] R. Stevens, K. O'Connor, L. Garrison, A. Jocuns, and D. M. Amos, "Becoming an Engineer: Toward a Three Dimensional View of Engineering Learning," *Journal of Engineering Education*, vol. 97, no. 3, pp. 355–368, 2008, doi: 10.1002/j.2168-9830.2008.tb00984.x.
- [6] A. Godwin, "The Development of a Measure of Engineering Identity," in *2016 ASEE Annual Conference & Exposition Proceedings*, New Orleans, Louisiana, Jun. 2016, p. 26122. doi: 10.18260/p.26122.
- [7] S. Sheppard *et al.*, "Exploring the Engineering Student Experience;," p. 231.
- [8] "Statistics Roundtable: Likert Scales and Data Analyses." <http://rube.asq.org/quality-progress/2007/07/statistics/likert-scales-and-data-analyses.html> (accessed Feb. 15, 2021).
- [9] R. F. Woolson, "Wilcoxon Signed-Rank Test," in *Wiley Encyclopedia of Clinical Trials*, American Cancer Society, 2008, pp. 1–3. doi: 10.1002/9780471462422.eoct979.
- [10] J. Kruger and D. Dunning, "Unskilled and Unaware of It: How Difficulties in Recognizing One's Own Incompetence Lead to Inflated Self-Assessments," *Journal of Personality and Social Psychology*, vol. 77, pp. 1121–34, Jan. 2000, doi: 10.1037//0022-3514.77.6.1121.

