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Neurocognitive Examination of the Impact of Design Project Representation on Student Motivation and Performance

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Abstract

The ASME Vision 2030 Project (V2030) outlined a set of goals to aid in the development of engineering education to better face the current and future demands of the profession. Part of this vision proposed the implementation of designed-based curricula throughout the degree program. These design courses are meant to introduce students to implementing theoretical knowledge into real-world applications and design tasks. The purpose of this preliminary study is to investigate the impact of design courses on the neurocognition of mechanical engineering students. This study utilizes a group of students in a sequential series of cornerstone design courses. The study makes use of an electroencephalography (EEG) device to monitor the participant's brain activity during a design task. This data will compare brain activity when the participants are presented with differing modalities of design exercises. A modified version of the Motivated Strategies for Learning Questionnaire (MSLQ) will self-assess the student's motivation toward the design tasks.

The robustness of this study allows for the ability to examine the impact of both brain activation, motivation, and learning style on the student's design. Motivation, brain activation, and learning style are measured regarding a student's demographics, including gender, residency, and age, to determine if a correlation is present.

The results of the study indicate that there is a correlation between change in brain activation in the beta frequency located in the right frontal cortex and design problem modality. These findings further present a strong correlation between the brain activations and self-reported motivations of the students. Specifically, a student's cognition motivation had a positive influence with design problems presented as pictures. Further it was determined that a kinesthetic learning style benefitted from pictural design problems, as well.

Introduction

Engineering education is a dynamic field influenced by the industry's shifting demands. The American Society of Mechanical Engineers (ASME) Vision 2030 Project (V2030) has identified several goals that are crucial for the preparedness of future engineers. One goal is to enhance "Student design/build project experiences in the degree program" [1]. However, this goal challenges educators as they strive to implement it effectively.

Implementing the goal poses a challenge for educators as it leaves many decisions to be made, which should only be done with consideration for the students. One crucial factor to consider is the academic major of the students. As demonstrated by Vieira, the regions of the brain utilized for a task vary depending on the subject's expertise or field of study. The study outlines the differences in the brain regions used by mechanical engineers from those used by architects [2]. Another crucial factor to consider is the motivation of the students toward these design experiences, especially throughout the curriculum. Research on student motivation has proven the dynamic nature of motivation, even over a short time. Another study has shown that essential motivation factors also vary with the study year the student is currently enrolled in [3]. Additionally, the influence of the presentation of problems in design projects is an important aspect that educators may consider. In a focused investigation, Gero [4] compared the effects of constrained and open-ended design problems. Some other considerations in understanding these influences have been presented, such as learning styles and personality types. However, studies have yet to compare the modality of design problem statements and the impact on student's motivation towards completion.

This study aims to determine if the modality of a design problem affects the thinking of mechanical engineering students (measured through brain activations), and if these correlate with a student's motivation or preferred learning style. This study utilizes electroencephalography (EEG) to determine the brain activations of students in the cornerstone design course at Florida Polytechnic University. This course introduces mechanical engineering students to fundamental design practices and skills in the student's sophomore year. The goal is to determine if there is any change in brain activations between design problems presented in two differing modalities – design problems presented through a textual prompt and design problems presented purely pictorially. A further goal of this study is to determine if there is any correlation between brain activations and academic motivation or learning style. Therefore, student motivation is measured by Pintrich's Motivated Strategies for Learning Questionnaire (MSLQ), which will be discussed further in a future section of the paper [5]. Another possible scope for influence is the student's preferred learning style, as determined by Fleming's VARK [6]. A final frame to be investigated is if the demographics of a student, such as gender and socioeconomic status, influence brain activation when presented with a design problem.

This research aims to provide insight into how design problems should be presented to students in design courses. If it is determined that there is a correlation between brain activations and any specific motivation or learning style, this can prove vital to an educator. Utilizing either of these questionnaires, an educator could target the specific needs of each student, ensuring their success in the course and improving their overall understanding of the course material. This study explicitly addresses three research questions about the modality of design problems in a design course.

- In what ways does the change in design problem modality alter brain activations?
- What motivation factors correlate with variance in brain activations due to the change in design problem modality?
- What preferred learning styles correlate with variance in brain activation due to the change in design problem modality?

Background

It is imperative to understand the pretext that inspired the authors to conduct this research and utilize the tools outlined. A brief history of the goals of ASME and the field of design neurocognition that inspired the research is presented to understand the motivation of the researchers. The EEG is a widely used tool by researchers to provide quantifiable data of brain utilization. Using this data, and decades of neurological research, researchers can determine in what ways the participants' brain is functioning without interference of any bias. Also utilized in this research are the MSLQ and VARK surveys, providing insight into the self-perceived motivations and preferred learning styles of the students. Utilizing these tools and demographic information gathered, a diverse and thorough amount of data can be utilized as we investigate the influences that affect a participant's alteration in brain activations due to differing design modality.

1. ASME Goals and Neurocognition

The ASME V2030 laid out essential goals for educators to achieve by the end of the decade. These goals were not simply determined by a small contingent of people, but rather done by a task force that surveyed well over 3000 correspondents. These correspondents included 1470 senior engineers and engineering managers, representing companies with as small as 1 employee to as large as more than 46,800 employees, and having upwards of more than 30 years of experience. 42 responses were gathered from differing academic institutions, which resulted in a plenary, which further probed 85 department heads on questions relating to the survey. In a final addition, 635 responses from early career (0-10 years of experience,) were gathered to provide a third perspective on the strengths and weaknesses of engineering education [7].

The survey presented 15 key skills and asked participants to determine which skills were strong and which were weak. As presented by both Danielson and Kirkpatrick, there exists a large gap between the reported strengths and weaknesses by industry supervisors when compared to the educator and early career engineers [7]-[8]. Focusing on the highest rated weakness by industry denoted as "practical experience," Kirkpatrick provides a recommendation of the incorporation of "curricular components that emphasize active, discovery-based learning…" [8]. Sheppard proposes that the design projects present an opportunity for professional development in skills such as formulating and problem solving [9]. One method of determining the ideal approach of this is through design neurocognition. This method provides an invaluable unbiased insight into a student's thought process. This is done through providing quantitative data that can be related to the actual processes undertaken by the student.

As explained by Gero [10], previous research into design has been evolved by the availability of non-invasive brain measurement devices such as EEG and fNIRS (a tool that measures hemoglobin concentrations,) and to a lesser extent fMRI (a tool that measures blood flow.) Each of these devices is designed to non-invasively measure cerebral activations. The EEG device collects brain waves, which indicate activations of certain areas of the brain. Utilizing knowledge gathered through neurological research, these brain activations can be correlated to differing brain processes. This technology has been utilized in a wide range of studies in effort to aid designing protocols and the development of curricula for engineering students.

In a study conducted by Vieira, an EEG device was utilized to display the difference in brain activations between constrained and open design problems [11]. Similar research has also been conducted with differing constraints, such as sustainability [12]. Furthermore, there has been a great deal of research into how differences between engineers affect brain activations when given the same task. Some studies looked at the influence of majors, with one study focused on differences in brain activations between mechanical engineers and architects [2], and a second focused on the differences between mechanical engineers and industrial designers in open versus closed design problems [11]. The effect on gender has also been observed in designing tasks conducted by industrial designers indicated that differing regions of the brain are utilized for opposing genders [13]. One final example of the breadth of the use of EEG in neurocognition research, is in the comparison of brain activations experienced professionals versus novices of their field. One such study compared experienced and novice designers [14], and another compared experienced and novice jazz performers [15]. This study seeks to further explore some of these phenomena.

2. The Brain and EEG device

To best understand results of the EEG it is imperative to understand the anatomy of the brain and the importance of each part. The brain is divided into 3 main regions, the cerebrum, cerebellum, and the brain stem. The main region of interest is the cerebrum, also referred to as the neocortex. This is the place where most of the brain processes take place, such as thought, speech, problem-solving, emotions and learning. The cerebrum is split into two halves, split longitudinally from back to front, with each side controlling the opposite side of the body it is on. The brain stem is vital to survival containing the medulla which regulates many of the body functions (heart rhythm, breathing, and oxygen levels to name a few) but also generates responses to stimuli in the midbrain. The cerebellum coordinates the muscle movements of the body and maintains equilibrium in posture. New studies show that the cerebellum may also play a role in thoughts, emotions, and social behavior [16].

There are four lobes in the cerebrum, the frontal, parietal, temporal, and occipital. The frontal lobe is responsible for the person’s movement, decision-making, and personality characteristics. It also contains the Broca area, which is associated with speech. The parietal lobe involves identification of objects, spatial relationships, and plays a role with touch in the body. The parietal lobe also contains Wernicke’s area which aids in spoken language interpretation. The main role of the occipital lobe is interpreting vision. The temporal lobe is the location where short-term memory, speech, and rhythm. There are also structures deeper in the brain, however, EEG devices do not measure these deeper systems, but can only measure the surface of the brain lobes [16]. With this basic explanation of the brain and how different regions are responsible for differing actions, it is next important to understand how the brain functions on a cellular level, which is with brain waves.

The brain functions by sending electrical potentials between neurons, and an EEG measures these potentials on the surface layer of the cortex. However, these are not a direct measure of information, however based upon the potential and frequency of the EEG, these can be measured as waves. Over the many years of neurological research, these waves have been associated with different activities. There are five identifiable brain waves that range from 0 hertz to 100 hertz. The highest frequency brainwaves are identified greater than 30 hertz, known as Gamma waves. These are associated with peak levels of concentration and high levels of cognitive function.

However, these gamma waves are hard to measure as the electrical signals from the muscles cause a great number of artifacts in this range with current EEG technology. For this reason, these brainwaves may be difficult to measure, however in this study were able to be recorded without a great amount of interference [17].

The next lowest brain waves range between 12 and 38 hertz and are referred to as Beta waves, which are categorized into Low Beta, Beta, and High Beta. Beta waves in general are associated with alertness, attentiveness, and problem-solving. Low Beta (12-15 Hz) are often referred to as "fast idle" or musing thought, which is considered deep thought like meditation. Beta (15-22 Hz) is associated with engagement and active problem-solving. High Beta (22-38 Hz) waves are correlated with highly complex thought, integration of new experiences, or excitement. Due to these high frequencies, these can often manifest in neurological issues like insomnia and mania. The next lowest brain waves range between 8 and 12 hertz and are referred to as Alpha waves. These waves are often associated with the brain's resting state, often associated with coordination, calmness, and learning. It has also been noted that following completion of tasks, post reinforcement synchronization (PRS) occurs which is a burst of alpha waves as the brain consolidates information. [17]

The last two brain waves range between 1 and 8 hertz, with theta waves ranging between 4 and 8 hertz, while delta waves range between 1 and 4 hertz. Both are associated with sleep, while theta waves occur during drowsy states. The only time these waves occur when a subject is awake indicates learning disabilities or other conditions, such as Attention Deficit/Hyperactivity Disorder (ADHD) [17]. A last area of interest concerned with brain operation is how memories are formed and stored in the brain. Three forms of memory exist, implicit, explicit, and working memory. Implicit memory occurs in regions of the brain too deep to be measured by an EEG device. However, explicit memory which is linked to episodic (past events), and semantic (general knowledge) memories have been linked to the neocortex. Working memory, also known as short-term memory, has been exclusively linked to the prefrontal cortex [18]. Utilizing this knowledge of the brain, when analyzing brain activation gathered by the EEG device, it can be determined the processes being undertaken by the participant.

3. Student Motivation

When observing the success/shortfalls of a student, many components are attributed to the reason behind their success/shortcomings. One aspect of students often overlooked is their internal motivation factors. These internal motivations are heavily influenced by many factors in a student's life. As displayed by Kirn, one such influence can be the major a student is pursuing [19]. Along with varying by year of study, another study showed that the motivation of students is not stagnant but evolves throughout their time studying, with some motivation factors becoming more important than others [3]. There are multiple questionnaires that investigate the motivation of students, for this study the MSLQ is utilized.

The MSLQ is a self-assessment questionnaire utilizing a Likert scale, rating a list of questions on a scale of "not true to me" to "very true to me." This study specifically views five motivation factors, which are gathered using this questionnaire: cognitive value, self-regulation, anxiety, intrinsic value, and self-efficacy. Cognitive value describes the ability to recognize required tasks and sequence of tasks to execute a design problem. Self-regulation is the ability to orient oneself in the completion of a goal or design challenge. Anxiety is related to the nervousness felt while completing the design activity. Intrinsic value describes the self-determination and internal reasoning of a participant in a task. Self-efficacy is confidence in achieving a goal [20]. Notably, it has been documented that self-efficacy of a student may increase or decrease depending on the task [21]. Therefore, different design tasks may increase or decrease the student's confidence in their ability to complete (whether successfully or unsuccessfully) a task.

The MSLQ offers a brief, but insurmountable insight into the motivations of a participant. It proves a useful tool in aiding educators in formulating education better suited to the individuals in their classrooms. In combination with brain activations, the MSLQ could possibly prove to be a further useful tool for educators. Pending the results of this investigation, motivations of the MSLQ could be linked to certain design modalities.

4. Learning Styles

Learning and retaining information through varying methods is a thoroughly researched area of education. Many methods exist to gage the preferred learning styles have been touted, including the method presented by Fleming known as the “VARK” in 1992 [6]. Fleming [22] further expanded upon this questionnaire, presenting the concept of multi-modal learning. The VARK is a self-assessment questionnaire in which students are asked questions based on different situations or preferences. The multiple-choice responses correlate to the outlined methods of learning, visual, auditory, reading, or kinesthetic. Summing up the number of indicated responses for each learning style, it can be determined which is the preferred learning style of the participant. Similarly, to the MSLQ, VARK may prove to be an even more useful tool for educators if there is a link between a preferred learning method and design modality.

Experimental Procedure and Analysis

The study was conducted in a single instance, at the end of a students’ first semester cornerstone course taught at Florida Polytechnic University. This cornerstone design course is commonly taken during the students’ sophomore year. In this course, students are introduced to the basic design concepts. Ideally this limits the amount of influence on how the participants approach the design problems presented.

For the study, participants were given a 30-minute time slot in which the experiment would be conducted. The participants were read a summary of the purpose of the study and what data would be gathered and utilized as approved by the university’s Internal Review Board (IRB). In conducting product comparison, it was determined that the EEG device best suited for this study is the Emotiv EPOX Flex 32 electrode cap [23]-[26]. The EEG cap was fitted to the participants, and utilizing a saline solution, the electrodes were soaked and placed as close to the scalp of the participant as possible to limit interference. Utilizing the EmotivPRO application, the contact quality (which is a metric used to determine if an electrode is properly attached) was assured to be close to 100%. Participants were advised to limit motion as this could worsen contact quality by shifting the EEG cap and cause artifacts in the EEG data.

A written design problem (designated as "Design Problem 1") was given to participants and they were advised to fabricate as many solutions as they see fit for the problem. Participants were given up to 10 minutes for this task, after which they were instructed to stop designing. A break of approximately 3 minutes was given; this was done to prevent fatigue as this would decrease performance in subsequent tasks [27]. A pictural design problem (designated as "Design Problem 2") was given to the participants with the same direction and time limitation as Design Problem 1. The design problems were all similar complexity. Following completion of Design Problem 2, participants were given a brief post-experiment questionnaire and this portion of the study was complete. The MSLQ and VARK were disseminated using the courses' Canvas page, and the participants completed these within a few days of the EEG portion of the study.

1. Study Subjects

The demographic information of the students who participated in the study was limited due to a small number of participants (n=12) as provided in Table 1. The participants were 83% male, 8% female, and 8% nonbinary. Of this group 75% identified as Caucasian/White, while 25% identified as Asian. It can be noted that all participants were in the same age range (17-20), and all were domestic (from the United States) students. Due to this limited range in demographic diversity, significant conclusions could not be reached regarding relations between demographic factors and brain activations.

Table 1: Participant Demographics

	Caucasian/White	Asian American	Total
Male	8	2	10
Female	1	0	1
Non-Binary	0	1	1
Total	9	3	12

2. Analysis Performed

The analysis performed will seek to address each of the research questions posed at the beginning of this paper. Firstly, the brain activations of the participants were averaged across all brain regions monitored and across all brain waves monitored (Theta, Alpha, Beta Low, Beta High, and Gamma,) for both Design Problem 1 and Design Problem 2. The statistical analysis of a t-test was applied comparing the averages, but also applied to the raw data of each brain wave across the different brain regions. In the results, $\alpha < 0.05$ is considered significant. This would address the first research question, specifically narrowing down which waves and regions of the brain are affected by design modality change.

To address the second and third research questions, the deltas between Design Problem 1 and Design Problem 2 were found across all brain regions and brain waves. Linear regression is utilized to compare the deltas to the motivation and preferred learning style of the student. This linear regression is utilized to determine if there is any correlation between the set of independent variables and dependent variables. Due to the presentation of multiple variables, correlations might be present as a multi-order level, and as such, Akaike's Information Criterion (AIC) is utilized to find the best fit model. Utilizing this method of linear regression, a correlation between a students' motivation or preferred learning style and brain activation changes could be determined.

Results

This section will discuss the presence of any brain activation difference between Design Problem 1 and Design Problem 2. This was done across the five brain wave frequencies and the 32 regions monitored. MSLQ and VARK were utilized to determine factors for any significant changes in brain activations. The MSLQ utilizes a Likert scale of 1-7, 1 indicating "not true to me" to a question and 7 indicates that the question is "very true to me." The VARK instructs the participant to select an answer or multiple answers to a question, which correspond to one of the four learning styles, each participant's answers for each learning style were totaled.

1. Difference in Brain Activation

The brain activations were averaged across all brain waves and across all brain regions for each Design Problem. Utilizing a t-test, it was determined that there were significant changes in brain activations across multiple regions and across the varying waves. To further the conclusions of the results, a t-test was applied to each set to the individual brain waves to decisively determine which brain wave(s) and brain regions caused these strong correlations. The results of this test indicated that the Beta Low frequency was the most significant brain wave, with the regions of Fp1, F3, FC5, P8, Cp6, T8, Ft1, Fc6, F4, F8, and Fp2 having statistical significance. When comparing the deltas between the two Design Problems, it can be noted there is a general increase in brain activation for Design Problem 2 compared to Design Problem 1. These results are displayed graphically in the polar plot provided in Figure 1.

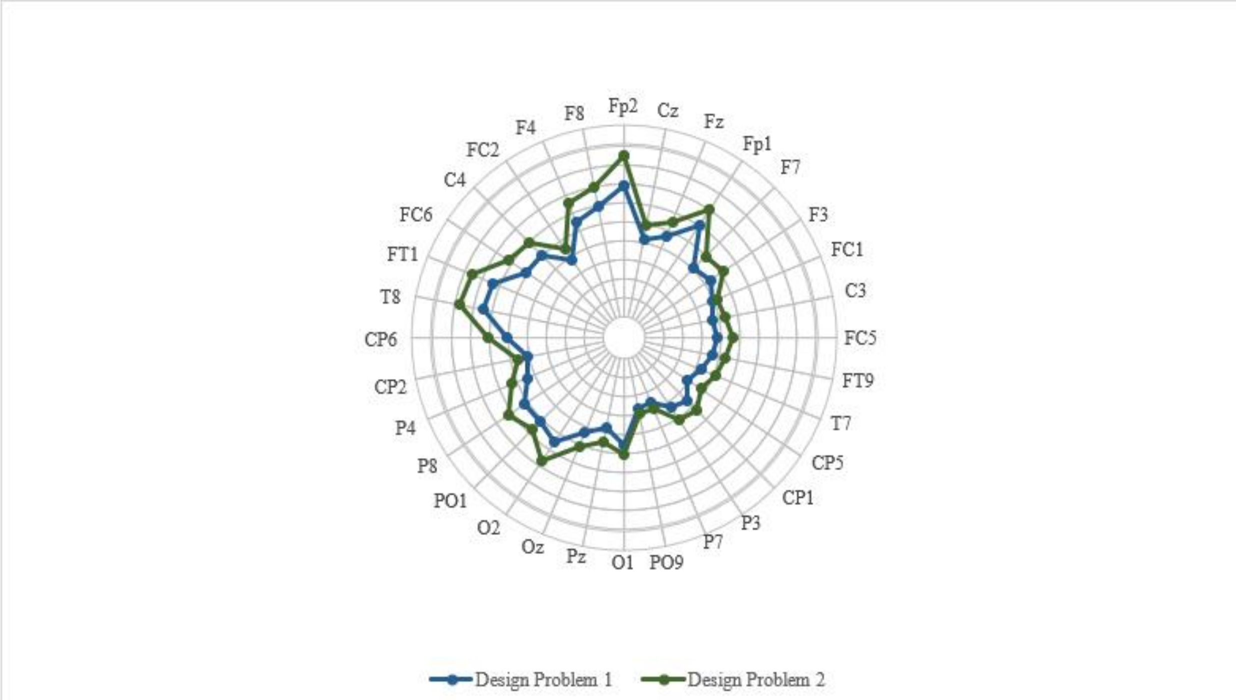
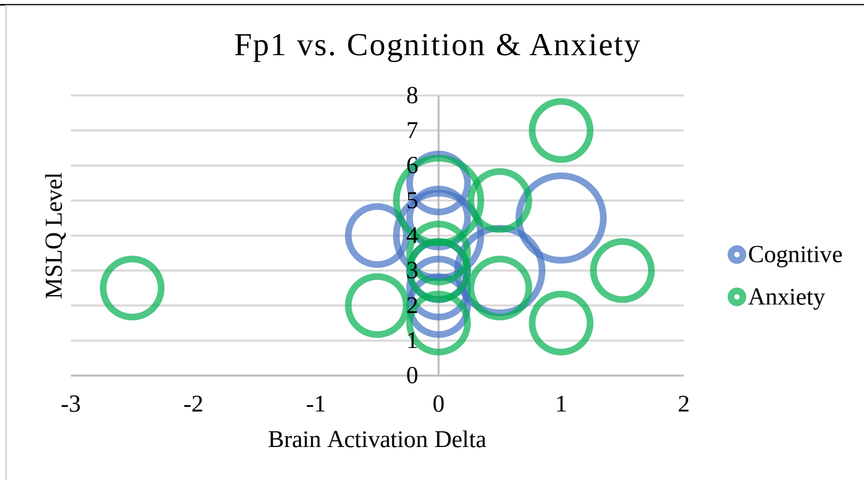


Figure 1: Change in Brain Activations in the Beta Low Frequency

2. Correlations Between Brain Activations and MSLQ

With the significant difference discovered in the Beta Low frequency and in the ten different brain regions, it was next to be determined if these changes could be correlated with motivation factors. For each of the significant brain regions a linear regression analysis was performed to determine which of the five motivation factors correlated to the change in brain activation. The AIC Analysis determined that Cognitive, Intrinsic, and Anxiety had the greatest correlation to change in the regions of Fp1, F3, FT1 and Fp2 (model p-value range = 0.0044 - 0.0477).

Figure 2 compares the brain activation in the Fp1 region to the participants' self-reported cognitive value. The students' cognition showed a positive correlation with their brain activations in this region. This was further exacerbated by the students' self-reported anxiety, however, the students' anxiety was negatively correlated with their brain activations in the Fp1 region. Recall, the Fp1 region is the prefrontal cortex, associated with tasks such as object identification and their spatial relationships.

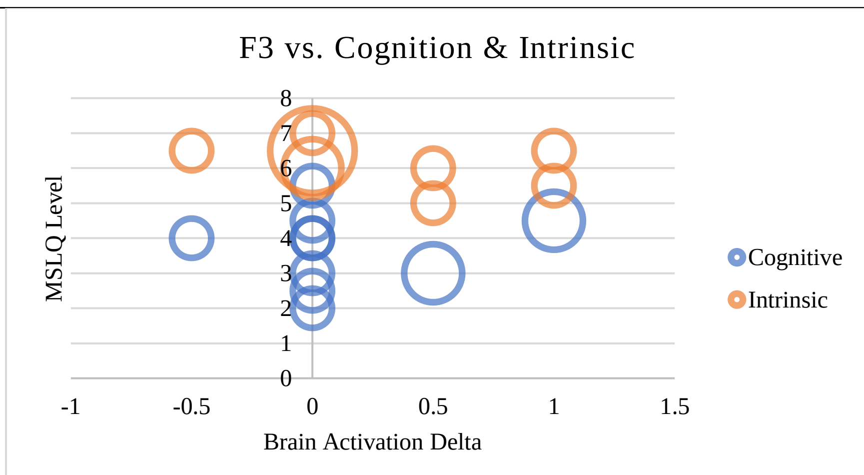


	Coefficients	*Std. Error*	*t Stat*	*P-Value*
Intercept	-2.938	0.7700	-3.815	0.0041
Cognitive	1.640	0.2943	3.944	0.0033
Anxiety	-0.0341	0.1679	-2.033	0.0726

Residual Standard Error: 0.6226
F-Statistic: 8.69
Model P-Value: 0.0079

Figure 2: Change in Brain Activations in Fp1 Compared to MSLQ

The students' cognition was also found to be positively correlated with their brain activations in the F3 region, which is in the frontal cortex and is primarily responsible for decision making. This relationship was strengthened by the negative correlation with their intrinsic value, to a model p-value of 0.0437. This is shown in Figure 3, below.

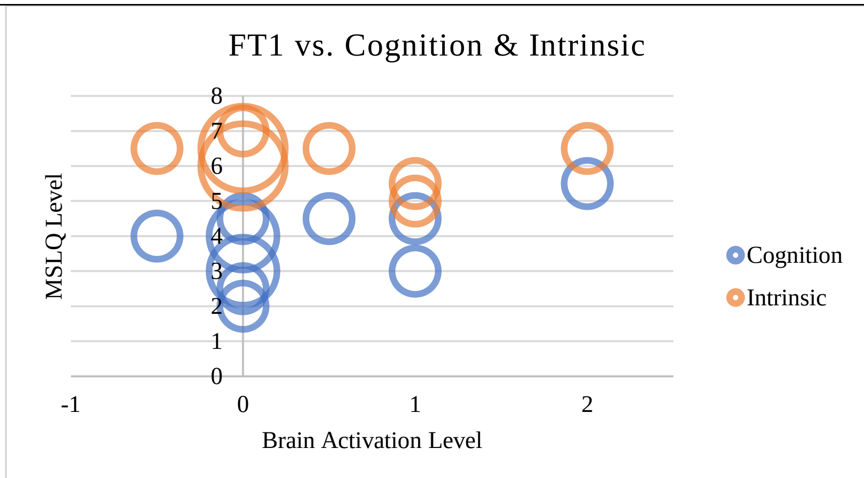


	Coefficients	*Std. Error*	*t Stat*	*P-Value*
Intercept	2.481	1.1717	2.056	0.0700
Cognitive	0.1940	0.0997	1.946	0.0835
Intrinsic	-0.4673	0.1870	-2.499	0.0339

Residual Standard Error: 0.3109
F-Statistic: 4.522
Model P-Value: 0.0437

Figure 3: Change in Brain Activations in F3 Compared to MSLQ

Figure 4 also exhibits the impact of the students' cognition and intrinsic value on their brain activations, this time with respect to FT1. FT1 is in the frontal temporal region of the brain, primarily utilized in decision making and recalling short term memory. Again, cognition exhibited positive correlation and intrinsic exhibited negative correlation.

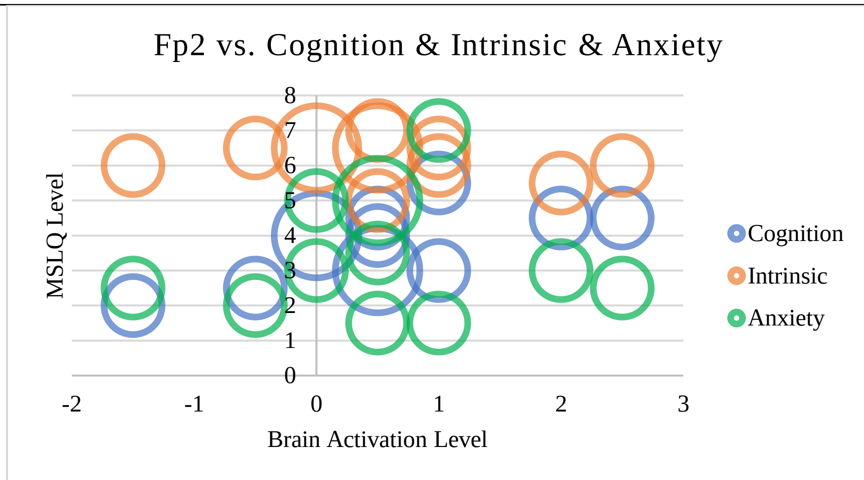


	Coefficients	*Std. Error*	*t Stat*	*P-Value*
Intercept	2.621	2.052	1.277	0.2355
Cognitive	0.4305	0.1746	2.366	0.0358
Intrinsic	-0.6215	0.3274	-1.899	0.0900

Residual Standard Error: 0.5444
F-Statistic: 4.369
Model P-Value: 0.0472

Figure 4: Change in Brain Activations in FT1 Compared to MSLQ

Finally, Figure 5 displays the impact of all three of the aforementioned significant motivation factors – cognition, intrinsic value, and anxiety – on brain activity in the Fp2 region. This region was found to be correlated with all three factors to a model p-value of 0.0041. Similar to the previous regions, cognition displayed a positive correlation with brain activations, while intrinsic value and anxiety displayed negative correlations. The Fp2 region is once again in the prefrontal cortex of the brain. This, coupled with the activations in the Fp1 region, displays cross-hemispherical activation in the prefrontal cortex, suggesting that participants use left- and right-brain operations.



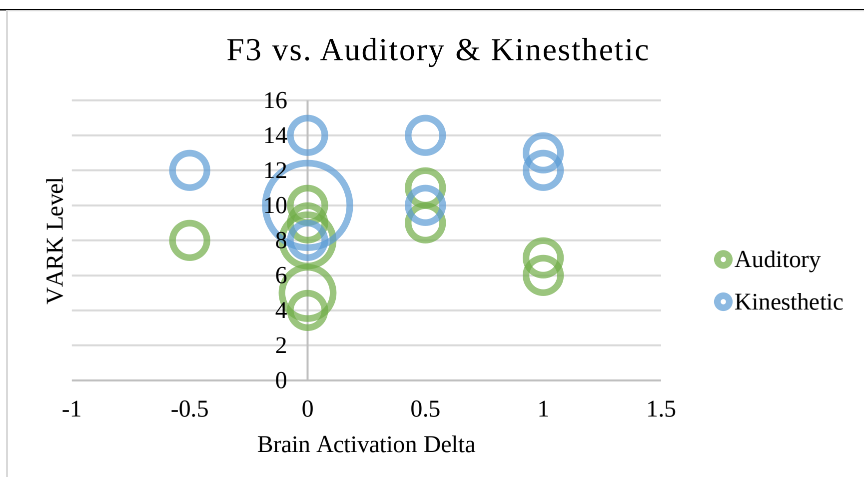
	Coefficients	*Std. Error*	*t Stat*	*P-Value*
Intercept	0.2473	2.0466	0.121	0.9068
Cognitive	1.374	0.2543	5.404	0.0006
Anxiety	-0.5628	0.1451	-3.877	0.0047
Intrinsic	-0.0455	0.3238	-1.406	0.1973

Residual Standard Error: 0.5376
F-Statistic: 10.22
Model P-Value: 0.0041

Figure 5: Change in Brain Activations in Fp2 Compared to MSLQ

3. Correlations Between Brain Activations and VARK

Like the MSLQ data, a linear regression analysis was performed to determine whether learning styles correlated to changes in brain activation. The AIC Analysis determined that Auditory and Kinesthetic had the greatest correlation to the region of F3, F4, F8, FC5, FC6, and CP6.

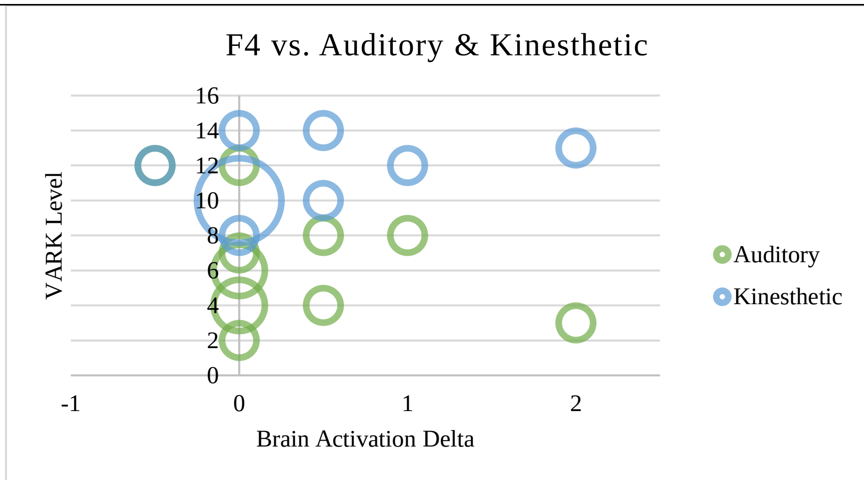


	Coefficients	*Std. Error*	*t Stat*	*P-Value*
Intercept	-1.328	0.5055	-2.627	0.0275
Auditory	-0.1112	0.0313	-3.549	0.0062
Kinesthetic	0.2040	0.0543	3.760	0.0045

Residual Standard Error: 0.262
F-Statistic: 8.209
Model P-Value: 0.0094

Figure 6: Change in Brain Activations in F3 Compared to VARK

The change in brain activations was found to be correlated to the auditory and kinesthetic learning styles to a p-value of 0.0094 and 0.0025 in the F3 and F4 regions, respectively. This again exhibits cross-hemispherical activations, this time occurring in the frontal cortex of the brain. The correlation between learning styles and activations in the F3 region are shown above in Figure 6, while the correlation between learning styles and activations in the F4 region are shown below in Figure 7. It is important to note that the kinesthetic learning style exhibited positive correlation, while the auditory learning style exhibited negative correlation for each of these regions.



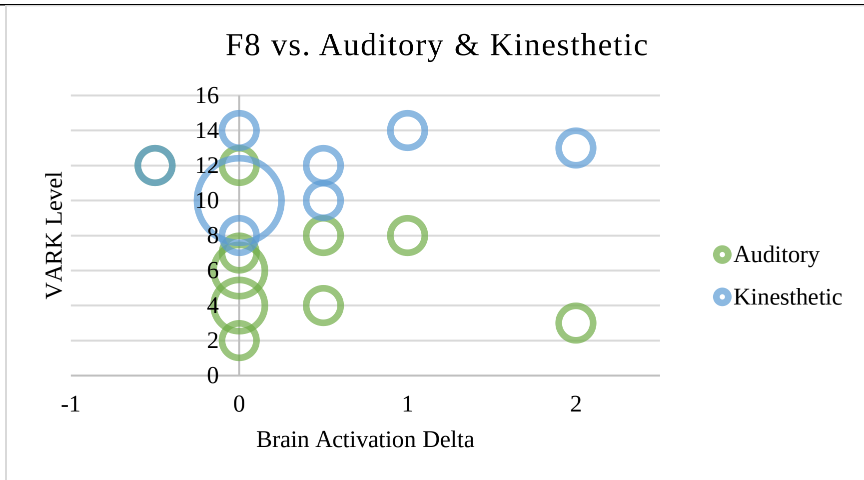
	Coefficients	*Std. Error*	*t Stat*	*P-Value*
Intercept	-2.213	0.6279	-3.525	0.0065
Auditory	-0.1615	0.0389	-4.150	0.0025
Kinesthetic	0.3227	0.0674	4.789	0.0010

Residual Standard Error: 0.3254
F-Statistic: 12.51
Model P-Value: 0.0025

Figure 7: Change in Brain Activations in F4 Compared to VARK

The auditory and kinesthetic learning style was also found to be correlated to the brain activity in the F8 region of the frontal cortex, shown in Figure 8.

Comparing the brain activations in F4 (Figure 7) and in F8 (Figure 8), it can be noted that the change in activations appear to be nearly identical when compared to learning style. This exemplifies an overall, equally proportional, increase in the right hemisphere compared to the left hemisphere.

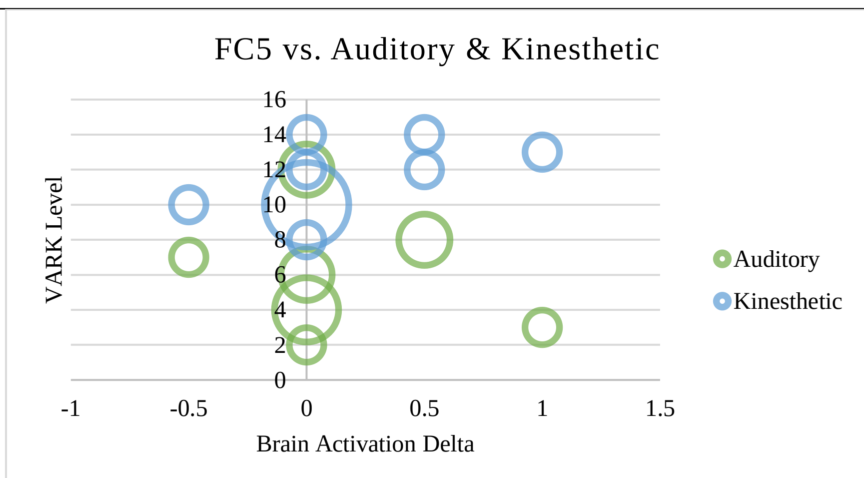


	Coefficients	*Std. Error*	*t Stat*	*P-Value*
Intercept	-2.438	0.5408	-4.507	0.0015
Auditory	-0.1720	0.0335	-5.131	0.0006
Kinesthetic	0.3459	0.0580	5.959	0.0002

Residual Standard Error: 0.2803
F-Statistic: 19.29
Model P-Value: 0.0006

Figure 8: Change in Brain Activations in F8 Compared to VARK

The students' auditory and kinesthetic learning styles were also correlated with the deltas in brain activations in the frontal cerebral cortex of the brain, specifically in the FC5 and FC6 regions.

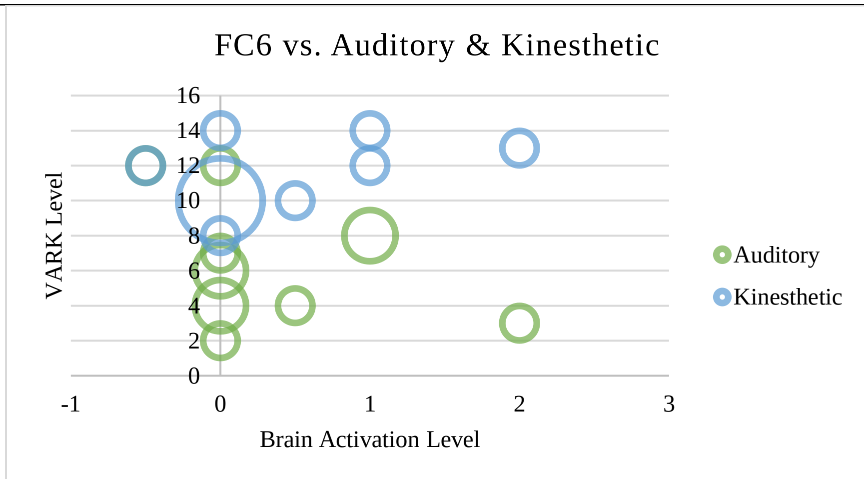


	Coefficients	*Std. Error*	*t Stat*	*P-Value*
Intercept	-1.305	0.4630	-2.819	0.0201
Auditory	-0.0995	0.0287	-3.470	0.0071
Kinesthetic	0.1930	0.0497	3.885	0.0037

Residual Standard Error: 0.2399
F-Statistic: 8.398
Model P-Value: 0.0088

Figure 9: Change in Brain Activations in FC5 Compared to VARK

The FC5 region (shown in Figure 9) and the FC6 region (shown in Figure 10) are responsible for planning and movement. Additionally, this exhibits cross-hemispherical activation, in which the plots are once again very similar in nature.



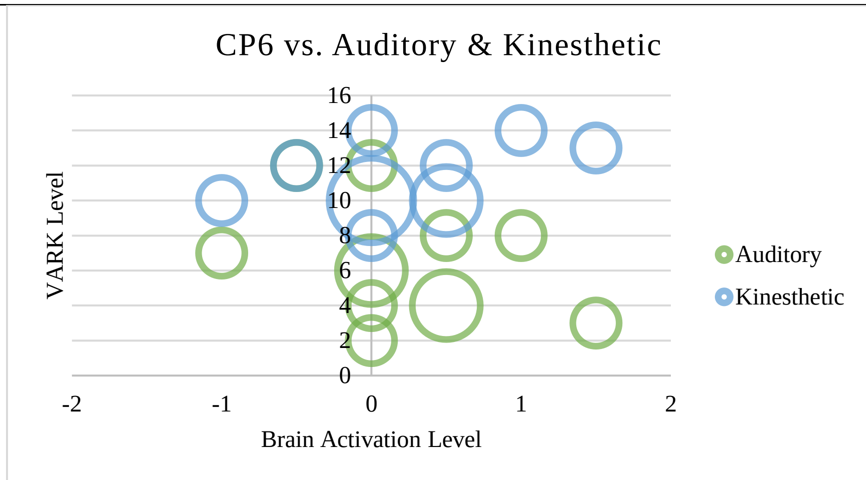
	Coefficients	*Std. Error*	*t Stat*	*P-Value*
Intercept	-2.494	0.6675	-3.737	0.0046
Auditory	-0.1797	0.0414	-4.343	0.0019
Kinesthetic	0.36082	0.0716	5.037	0.0007

Residual Standard Error: 0.3459
F-Statistic: 13.79
Model P-Value: 0.001815

Figure 10: Change in Brain Activations in FC6 Compared to VARK

Finally, the auditory and kinesthetic learning style were correlated to the changes in CP6, shown in Figure 11. Like all other comparisons to learning style, CP6 had a positive correlation to kinesthetic learning style and a negative correlation to auditory learning style.

The CP6 region is in the cerebral parietal area of the brain. This area is responsible for object recognition and interactions.



	Coefficients	*Std. Error*	*t Stat*	*P-Value*
Intercept	-2.294	0.5111	-4.489	0.0015
Auditory	-0.1733	0.0317	-5.472	0.0004
Kinesthetic	0.3252	0.0549	5.928	0.0002

Residual Standard Error: 0.2649
F-Statistic: 20.04
Model P-Value: 0.0005

Figure 11: Change in Brain Activations in CP6 Compared to VARK

Discussion

The findings presented in this research are unique due to the relatively new use of the EEG to gather insight into design cognition in the engineering education community. The changes in the brain activations of students between differing design problems are presented.

1. Significance of Brain Activation Differences

The beta frequency region being linked to attentiveness, problem-solving, and deep thought. It was found that of the 32 regions of the brain monitored, 11 displayed a significant level of change in brain activation between Design Problem 1 and Design Problem 2, specifically in the Beta Low frequency region, which is displayed along all regions in Figure 1. This parallels results presented by Vieira, in which it was recorded that when comparing closed- versus open-ended tasks, there was a significant difference in the beta frequency range [28]. The increase in this brain frequency from Design Problem 1 to Design Problem 2 indicates that the latter led to more investment and thought by the students. An increase in both could lead students to develop higher volume and higher quality solutions for design problems.

The frontal lobe has been linked to decision-making but also working memory, which is utilized during the completion of tasks for the generation of ideas. For the regions indicative of increased activation, four were in the left hemisphere (indicated by odd numbers,) and seven of these regions were in the right hemisphere (indicated by even numbers.) By region, nine of these regions are in the frontal cortex with one region in the temporal and one region in the parietal lobe. These are similar findings to Shealy, in which by using concept mapping in design, it was found there is an increase in right frontal cortex compared to the left frontal cortex [29]-[30]. The activations themselves also indicate an increased use of working memory in the students during Design Problem 2 [19]. Similarly to the beta frequency ranges, the activations of these areas of the brain suggest that the modality effects not only the student's investment into the design problem, but also bolsters the student's range of ideas, decisions, and reasoning processes.

In addressing the first research question – *In what ways does the change in design problem modality alter brain activations?* – we find that a positive correlation exists between an increase in brain activation and pictural design modality. This correlation specifically correlates in the beta low frequency region, furthermore in the right hemisphere of the brain and the frontal cortex of the brain. It is suggested to incorporate a range of design modalities to achieve the maximum effect of learning for the students.

2. Cognition, Intrinsic, and Anxiety Value Significance with Brain Activations

Changes in brain activations have a strong positive correlation between the frontal cortex and cognitive motivation. Cognitive motivation relates to a student's ability to identify required tasks and task sequence. Referring to Shealy, cognitive motivation closely aligns with the purpose of the frontal cortex, which correlates to increased use of divergent thinking and idea representation [29]-[30]. This correlation suggests that the students with higher cognitive motivation are more likely to produce solutions of a wider variety. As well these students can maintain the identification of the required tasks and sequence required for the design problem.

The negative correlation between anxiety, intrinsic motivation, and the students' increase in brain activation indicates several conclusions. During the design problems, and as displayed with Figure 2 and Figure 5, the students were less anxious while generating solutions for the second design problem. This correlation is directly aligned with an increased interest and engagement in this design problem. The decrease in intrinsic motivation, as displayed by Figure 3-Figure 5, indicates that the students had an increased difficulty in maintaining mental attention for Design Problem 1, as such, an increased difficulty in providing solutions. This can be accounted for by educators in that the first design problem is more demanding on students, which could cause students to dissociate with the design problem or the field.

In addressing the second research question – *What motivation factors correlate with variance in brain activations due to the change in design problem modality?* – we find that a positive correlation exists between a student's motivation and change in design modality. A positive correlation exists between pictorial design problems and cognitive motivation. An increase in cognitive motivation results in a wider array of solutions to design problems. A negative correlation between anxiety and intrinsic motivation exists and pictorial design problems. By decreasing these motivations in a student, less strain is applied to the student's mental capacity, resulting in a desired increase in ability to provide solutions.

3. Auditory and Kinesthetic Learning Significance with Brain Activations

Changes in brain activations indicates a strong positive correlation between the frontal cortex and the kinesthetic learning style, as displayed with Figure 6-Figure 8. The kinesthetic learning style is associated with a preference for "hands-on" open-ended learning, such as designing [6]. The pictorial presentation of Design Problem 2 leaves much open to the students to interpret when formulating solutions. For educators, the increase in activations could indicate students with this preferred learning style will be engaged by this design problem representation.

Opposingly the change in brain activations indicates a strong negative correlation between the frontal cortex and the auditory learning style, as displayed with Figure 6-Figure 8. This learning style focuses on the teaching method of verbal information presentation, such as lectures [6]. Design Problem 2 is directly juxtaposed to this learning style. Design Problem 2 leaves much to be interpreted by the students, while this learning style relies upon the presentation of direct instruction and information as seen in Design Problem 1.

In addressing the third research question – *What preferred learning styles correlate with variance in brain activation due to the change in design problem modality?* – it is found that there is a positive correlation between the kinesthetic learning style and an increase in brain activations. This indicates that the students with this preferred learning style were able to comprehend and provide more solutions. Contrastingly, there is a negative correlation between the auditory learning style and the increase in brain activations. Students with this preferred style likely had greater difficulty providing as many solutions, or grasping the task at hand. From this investigation of both learning styles, an educator may be inclined to provide both methods of design problem presentation depending on the student's preferred learning style.

4. Limitations of Study

The primary limiting factor of the study is the number of participants. This study is sufficient for addressing the three research questions investigated in this study, for future exploration. However, the limited demographic variation in the participants does not allow for sufficient comparison of other factors that likely impact the performance of a student. For example, Vieira investigated the difference in brain activations between male and female industrial designers and found key differences in both frequency bands and brain regions [14]. This may be another key consideration for educators to factor in when creating design problems and challenges.

A second limitation of this study is derived from the use of an EEG device. To attain proper data, the electrodes of the EEG device need to be placed on the scalp. It has been noted, and observed in this study, that this requirement excludes certain types of hair and hairstyles prominent in certain demographics [31]. This is an ongoing matter that has only had novel solutions presented. If a common solution has been developed, this would allow for the inclusion of more participants and a wider demographic range.

Conclusion

This study examines the brain activation changes in students when presented with differing design modalities. This study was performed using an EEG device to determine brain activations, MSLQ, and VARK surveys. This study identifies that there are significant changes in brain activations in the beta frequency range, specifically correlating with the frontal cortex and right hemisphere, between the two differing design modalities. This suggests the importance of incorporating varying design modalities to challenge students and provide more fulfilling learning outcomes. With such correlation existing, it was sought if these changes could further be correlated with a student's motivation and/or preferred learning style. The MSLQ survey indicated that there is a positive correlation between the students' brain activations and their cognitive motivation. The students' cognitive motivation describes their ability to identify the tasks, as well as the necessary sequence of tasks, to complete a design challenge. Therefore, the students' positive correlation between their brain activations and their cognitive motivation suggests that the students have an increased ability to produce a wide variety of design solutions when presented with the second design problem modality (pictorial). The VARK survey also indicated a positive correlation between brain activations and the kinesthetic learning style. This signifies the students' abilities to interpret the pictorial design problem due to increased engagement and visualization. The results also showed a negative correlation existing between brain activations in comparison to anxiety and intrinsic motivation, and the auditory learning style. The motivation is indicative of decreased attention, therefore decreasing the students' ability to provide feasible design solutions. Additionally, the auditory learning style is directly opposite to the kinesthetic learning style, as outlined by Fleming. The auditory learning style requires direct instruction and information, which aligns with the modality of the first textual design problem and opposes the second pictorial design problem. The goal is to continue examining these phenomena to provide improved pedagogical approaches for design curricula.

1. Future Works

Future work in this study includes the investigation of the change in brain activation and the quality of the design output. While this study focused on the quantitative intersection of brain activations, student motivation, and preferred learning styles, the study did not consider the quality of the design outputs generated by the students for Design Problem 1 and Design Problem 2. The next step is to generate a methodology to score the design output generated by the students and compare the quality of the designs generated with the data presented in this paper. This will allow for a better understanding of the impact of design problem modality on design output, including the consideration of brain activity. Additional considerations include generating a baseline comparison of brain activations to non-design-oriented tasks, to determine whether significant differences exist.

With a larger sample size, student demographics could also be compared, to determine whether trends exist. Additional student measures could be considered, as well; this could include various measures from the student's personality assessment, such as introversion/extraversion, student interest, and previous experience or expertise.

Additionally, Florida Polytechnic University currently offers a three-year design sequence in mechanical engineering. This presents an opportunity to consider a longitudinal study examining the impact of design problem modality on brain activity and the quality of design solutions at differing levels in the curriculum. Determining how these brain activations vary over the course of a student's experience in high level education can allow educators to better prepare coursework and information for the students.

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