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# Preliminary Results of a Pilot Study of Students' Phenomenological and Psychophysiological Reactions in Engineering Design

**Dr. Jennifer S. Atchison, Drexel University**

Jennifer Atchison received her Ph.D in Materials Science and Engineering in 2012 from Drexel University. Dr. Atchison's research interests include creativity in engineering design, exploring the influence of industry collaboration in professional formation of engineers, and broadening participation of BIPOC and women in Mechanical and Electrical engineering. Her teaching interests are focused on infusing a human centered perspective into Senior Design. She is the faculty advisor for ASME student organization, and I am ME! Drexel Women in Mechanical Engineering organization. She is a member of ASEE and ASME.

**Christine Chesebrough, Drexel University**
**Dr. Lutfi Agartan, Drexel University**
**Aaron Herbert Bernard**
**Jen Katz-Buonincontro**
**Evangelia G. Chrysikou, Drexel University**

Dr. Evangelia G. Chrysikou is an Associate Professor in the Department of Psychological and Brain Sciences at Drexel University, the Director of the Applied Cognitive and Brain Sciences PhD Program (https://drexel.edu/coas/academics/departments-centers/psychology/research/applied-cognitive-and-brain-science/), and the Associate Dean for Research for the College of Arts and Sciences. She is also the President of the Society for the Neuroscience of Creativity (www.tsfnc.org). She holds a Ph.D. in Brain and Cognitive Sciences from Temple University, where she also completed a year-long postdoctoral appointment in cognitive neuropsychology, followed by postdoctoral training at the Center for Cognitive Neuroscience at the University of Pennsylvania. Dr. Chrysikou uses cognitive neuroscience methods, especially functional brain imaging and noninvasive electric brain stimulation, to study cognitive flexibility and creative thinking and problem solving, as well as the implications of such flexibility for theories of creativity, semantic knowledge organization, and cognitive control.

# Preliminary Results of a Pilot Study of Student's Phenomenological and Psychophysiological Reactions in Engineering Design

Providing opportunities for students to practice creative design during their education is a priority for engineering instructors, but doing so effectively requires bridging the gap between the aims of creativity-based curricula and students' reported discomfort with taking creative risks in the classroom. One of the factors that may account for this discomfort is the consequences of instructor or peer feedback on students' creative thinking. Research that has examined the effects of feedback on student creativity is scarce. In this study, we used a mixed methods experimental design to capture the objective (psychophysiological) as well as phenomenological (self-report) measures related to students' arousal level and subjective experience when engaging in an open-ended engineering design task and being told that their work would be evaluated for creativity either by a faculty or a peer. Students in a pilot study were randomly assigned to either the faculty or peer condition. We predicted that anticipating evaluation from a faculty member would result in greater physiological arousal (measured via electrodermal activity) and would be associated with worse creative performance on the design task. Non-conclusive results from a pilot study ($n$ = 15) supported these hypotheses. In addition, study participants were interviewed about their experiences engaging in creative problem-solving in learning environments where they will be evaluated. Here, we report consistent themes from the interviews that highlight ways in which engineering educators may best support student creativity. In addition, we report several learnings from examining skin conductance measures that may be helpful for educators and researchers who are interested in the influence of arousal and emotions (positive and negative) during naturalistic learning and problem-solving.

## Introduction

The wicked problems society and humanity are facing today require engineers to cultivate a discipline of creativity in the ways they define problems and ideate solutions [1]. The UN Sustainable Development Goals, the National Academies, and other reports emphasize the need to produce engineers who can think creatively to live sustainably and include justice and equity in our engineering endeavors. Many environmental factors can affect a particular team's ability to creatively engage with a problem or design an innovative artifact. Teaching creativity in engineering education involves helping students develop the skills and mindset necessary for the psychological demands of innovative problem-solving.

Creativity in the context of engineering education is a process-mediated activity. Engineers use the engineering design cycle to activate their creative inputs, such as their curiosity (intrinsic motivation), domain-relevant skills and knowledge, and divergent thinking skills, such as brainstorming, bio-inspiration, bisociation, and pain storming to produce as many potential solutions as possible (fluency), that are appropriate to the problem. They then evaluate their potential solutions for appropriateness and feasibility within the constraints and specifications given. Most engineers select a solution (design concept) and enter the design, build, and test loop. There can be multiple ideation processes as additional problems arise, or a pivot occurs in the embodiment process. Though the same process can be applied to straightforward problems and problems that require out-of-the-box thinking, generating innovative, non-obvious solutions to engineering problems requires flexibility and a willingness on the part of the problem-solver to take risks. Yet, to do so, the individual or team must have tacit or explicit permission from the environment and/or stakeholders that deviating from obvious solutions will not be punished.

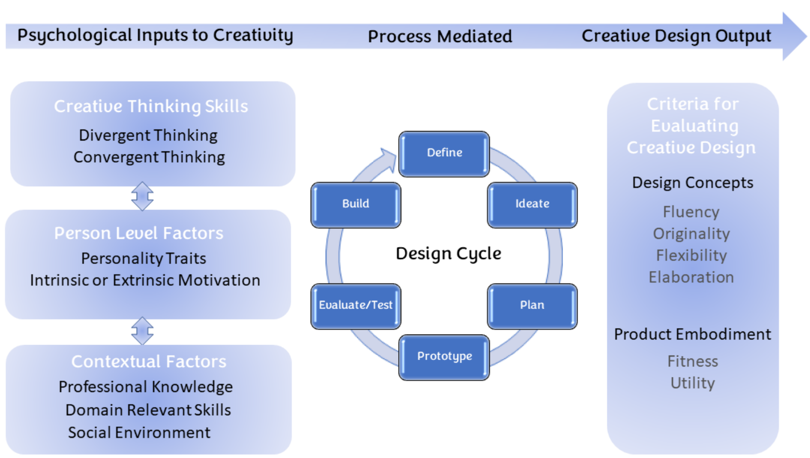


**Figure 1** *Diagram illustrating the relationship between creative thinking and creativity in Engineering Design. Creativity is associated with divergent and convergent thinking and there are person level factors and contextual factors that can affect a person's creativity. In engineering design, the psychological factors are also mediated by the process in the design cycle. The creativity of an engineering design is assessed by fluency, originality, flexibility and elaboration of the design concepts as well as the fitness and utility of the design embodiment.*

Taking creative risks during problem-solving is a skill that needs to be explicitly taught and fostered [2]. Students need to be given space to learn and persist through failure and have multiple opportunities to be creative once they are familiar with the tools and skills required to engage in their discipline and think creatively [3]. In some studies, for example, students have described their actual experience of being creative during course assignments as difficult and fraught with learning challenges, such as a "chilling" effect when working with the course instructor [4]. This suggests a disconnect between the learning objectives of creativity-focused course content and students' willingness and ability to engage in creative thinking in the classroom due to the stress-inducing presence of authority figures who explicitly or implicitly evaluate their work. Assignments intended to provide students with the opportunity to practice creative thinking may therefore be unsuccessful - or even harmful - if the constraints of a typical classroom environment prevent them from engaging meaningfully.

One of the primary sources of difficulty for students may be the presence of their instructor and the (implicit or explicit) expectation that their work will be evaluated according to rigid criteria that will not reward creative risk-taking. As a result, in the classroom, students often default to the most obvious solutions, especially in the presence of an instructor, due to the anxiety of being evaluated or the perception that risk-taking and creative skills are not a valued part of their education [5]. Therefore, the physical or imagined presence of an instructor with evaluative authority over their work may constrain students' creative ideation and problem-solving. However, the crucial role of feedback and the precise circumstances under which it can be beneficial or detrimental to student creativity is substantially understudied.

In scientific studies of creativity, creativity is assessed by evaluating the fluency, appropriateness, novelty/originality, and degree of elaboration of potential solutions. Though much of the psychological research on creativity uses short, domain-general ideation tasks, the same criteria of fluency, appropriateness, novelty, and elaboration can also be applied to more complex tasks that better mimic difficult design problems that engineering students often face. One such approach was reported by [6]. They compared the measurement of engineering and industrial design students' problem-solving along three dimensions: "expansivity" (capacity to explore the problem space), fluency (number of design solutions), and originality (degree of novelty expressed in designs). The control group's problem centered on "ensuring a hen's egg that is dropped from a height of 10 m does not break," whereas the fixation group's problem focused on the egg drop problem with the example of a parachute (pp. 315). The "fixation" example of the parachute appeared to hinder the expansivity, fluency, and originality of the students' solutions. However, originality and expansivity were significantly correlated. In this study, industrial design students generated more solutions and were less fixated than engineering students. This study illustrates the potential ways that undue constraints can negatively influence the creative design and suggests that other constraining factors, such as the expectation that one's work will be evaluated or the implicit presence of an instructor, may have a similar effect.

A challenge in the measurement of students' response to feedback during creativity tasks entails one's ability to precisely capture students' true affective response in anticipation of faculty or peer input on their creative output. Across disciplines, and especially within engineering design or other artistic domains, explicit, self-report assessments of one's own creative process or affective state through brief questionnaires, usually at the end of a creative task, are frequently influenced by students' tendency to conform to the instructors' expectations or the students' biases about creativity or their beliefs about their own creative potential. Indeed, a result of such biases is the difficulty in assessing the real impact of the expectation of feedback from one's peers or the instructor for the students' creative performance. On the other hand, not all affective response measures are explicit: psychophysiological indicators of effect, such as electrodermal responses (a.k.a., skin conductance), are powerful tools for capturing one's true affective state, as they are implicit, cannot be reflected upon, and are typically not amenable to participants' voluntary control.

Yet, both explicit (self-report) and implicit (psychophysiological) measures can capture different facets of complex behavior. A framework that combines phenomenological and psychophysiological indicators poses the possibility of a balanced and disciplined account of cognitive phenomena at multiple levels of analysis that can help bridge the biological mind-experiential gap [7]. Although limited in their scope, several recent investigations have provided evidence in favor of joint phenomenological and psychophysiological indicators of complex human experience. For example, combining a micro-phenomenological interview with behavioral and electrophysiological (EEG) brain activity measures allowed for a comprehensive examination of the relationship between emotional states, cognitive flexibility, and reaction time [8]. Similarly, self-reported empathy has been positively correlated with objective physiological indicators of pain [9], whereas electrophysiological data were able to distinguish between learners and non-learners in a neuro-feedback training task that tracked differences in the subjective experiences of each group as captured through a qualitative explication interview after the training session [10]. These results highlight the potential of mixed methodologies incorporating phenomenological (self-report) with objective (psychophysiological) measures for studying complex cognitive phenomena.

Given the tremendous potential consequences of feedback for students' creative output in the classroom, the proposed study will leverage phenomenological and psychophysiological methods to provide novel evidence on the socio-affective mechanisms underlying the effects of anticipated feedback for students' creative performance in a realistic engineering design task. Specifically, we investigated if evaluation-related anxiety reduces creativity, particularly when the student is anticipating evaluation by an instructor. And our mixed-methods paradigm will allow us, for the first time, to capture in detail how the anticipation of feedback from different sources elicits stress-induced psychophysiological responses that can predict possible changes in students' self-reported beliefs about creativity, as well as independent assessments of the creativity of the engineering designs.

## Experimental Design

In the present paper, we report findings from a pilot study of $n$ = 15 subjects. The pilot study aimed to test our experimental methods and examine participants' physiological responses to an open-ended creative design task in preparation for a more extensive study. Here, we report our methods, preliminary findings, and lessons learned from examining the rich data generated from this pilot experiment and discuss how we will apply these methods to a larger dataset currently being collected.

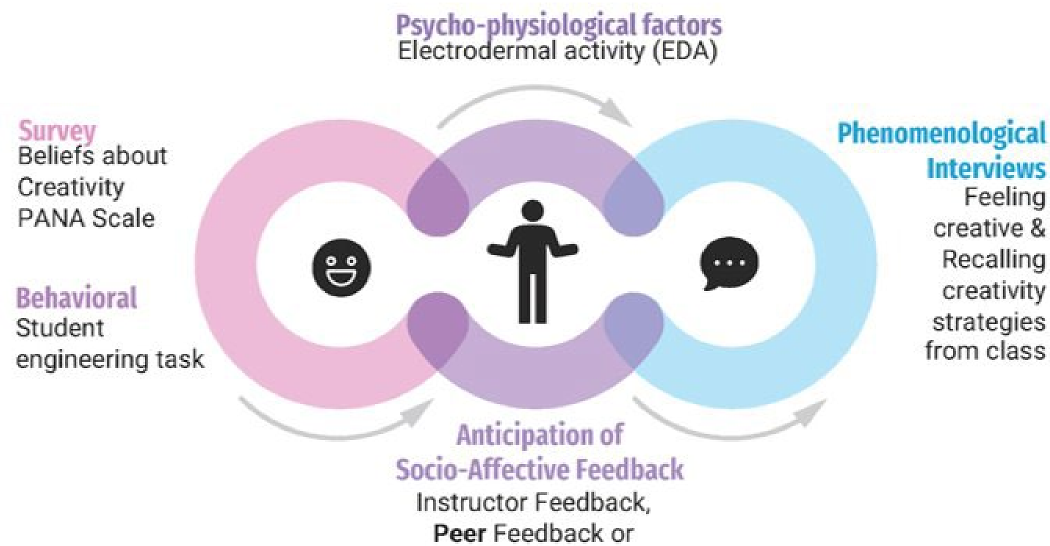


*Figure 2 Diagram of the mix methods approach developed for this study.*

## Participants

Drexel University undergraduates ($n$ =15) from engineering, chemistry, psychology, history, and graphic design were randomly assigned to one of two experimental conditions: the (a) expectation of faculty feedback ($n$ = 9); (b) expectation of peer feedback ($n$ = 6) (10 participants identified as female). Though participants had a range of academic backgrounds (see p. 14), the composition of the two conditions was equivalent in terms of the spread of majors.

## Equipment

Electrodermal activity was acquired using the Biopac MP160 system with the EDA100C amplifier and TSD203 electrodes attached to the middle and index finger of the participant's non-dominant hand. The data acquisition settings were a gain of 10µMho per Volt, a low-pass filter at 1 Hz, and a high-pass filter at 0.05 Hz. A DC voltage was not applied, meaning the electrodermal activity measured was endosomatic skin potential responses (SPRs) rather than exogenous skin conductance responses (SCRs). SPRs are highly correlated with SCRs and thus capture similar information about sympathetic nervous system activity, though their magnitude is considerably smaller, measured in nano siemens rather than micro siemens [11].

The physiological data were recorded and analyzed using Biopac's Acqknowledge software (v. 6). Questionnaires were administered using Qualtrics. The audio-visual recordings were captured via an overhead camera and microphone and stored on a lab PC running Windows 10 OS.

**Procedures**

The study was approved by Drexel University's Institutional Review Board (IRB approval number: 1902007025). Participants were asked to come to a lab space in the Psychological and Brain Sciences Department. After informed consent, participants completed a self-report assessment of their current affective state [12] and the Beliefs About Creativity Scale [13]. Next, the experimenter placed the EDA electrodes on the index and middle fingers of their non-dominant hand to record skin conductance and began recording. Participants' skin conductance was measured while briefed on the design task (Design Brief) and completed the design task (Design Activity). During the experiment, the investigator marked the beginning and end of the Brief and Design periods in the EDA signal.

*Brief Period*

First, participants were shown the design brief and were given instructions on how to complete the task. Next, they were told that they would be given 20 minutes to generate a solution to an open-ended design problem and that they should try to be as creative as possible in developing their solution. They were told that a "creative design" means that the solution they develop should be feasible and conform to the requirements of the brief but that it should be novel, i.e., something that others would be unlikely to think of and not a common existing solution. The design problem involves developing a knowledge retrieval system for a small-medium sized local library that would improve children and young adults' engagement with the library materials by helping them discover and access physical and digital library assets (books, periodicals, equipment, e-books, music, etc.) This knowledge retrieval system needed to include an interactive physical system that would be installed at the library but should also include a software component that indexed the library's catalog of physical and digital materials. This was intended to be an open-ended prompt that could be solved in many ways using a user-centered approach. Finally, participants were given reference photos, a budget, and approximate dimensions of the library and were told to be as specific as possible when describing their final design.

They were told that their design would subsequently be evaluated for novelty by a faculty member in the engineering department (faculty condition) or by a peer who had already completed the experiment (peer condition). In addition, they were told to expect feedback on their design via email from this individual within 3-5 days. They were also told that their hands would be recorded with a camera as they worked on their solution (using a pen and paper) and that they should verbalize their thought process aloud.

We anticipated that giving participants the expectation that they would receive feedback on their design and telling them that their problem-solving process would be recorded via video and audio would be experienced as (at least) moderately stressful. However, we predicted that the expectation of receiving feedback from a faculty member would be significantly more stressful than anticipating feedback from a peer. Though this experimental procedure doesn't exactly mimic a classroom setting, it was intended to introduce a reasonable amount of stress that reflects the pressures experienced by students when they know their work is being monitored and evaluated in learning environments. By introducing these naturalistic sources of stress, we can examine how different students respond to these pressures and whether it influences their creative output.

*Design Period*

Participants were given 20 minutes to complete their design. Their hands and speech were recorded with a camera and microphone. They described their thought process out loud while they developed their solution using a pen and paper. Following the design task, participants completed the PANAS mood scale once more to evaluate their mood.

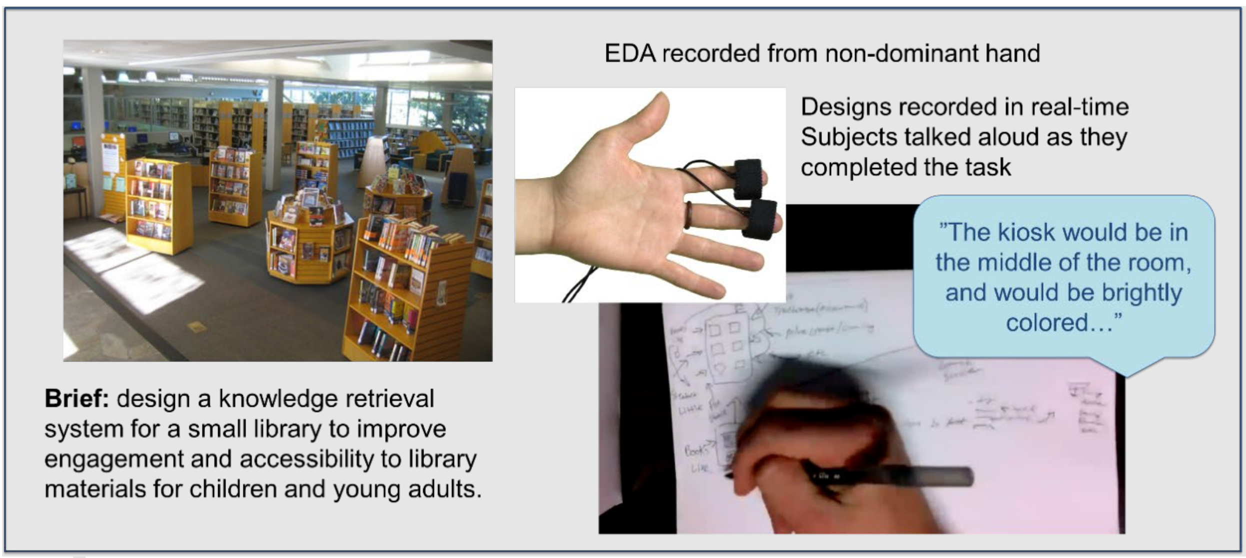


*Figure 3 Example reference photo and summary of the design brief given to the students, a photograph illustrating the placement of the electrodes on the hand, and a still image captured from the video recording of a pilot participant completing the design problem.*

## Post-design Interview

Next, the experimenter conducted a conversational qualitative interview about the participants' experience completing the design problem and their reflections on engaging in creative problem-solving in instructional settings. The questions below were asked in the order shown for all participants.

1. When you were completing the design task, how salient was the thought of the faculty member/peer evaluating your work? i.e., were you thinking about the person who was going to be looking at your work while you were completing the design?
2. What creative strategies did you use in this task that you may have learned in your university classes or elsewhere (e.g., in high school, via hobbies, etc.)?
3. How do your instructors (faculty, TAs, or co-op supervisors) influence your creativity? What is it like to work with them or get their input on projects?

4. How likely are you to take creative risks when you know your work is being evaluated by an instructor?
5. How do your peers, such as your classmates or team-mates in a work setting, influence your creative process?
6. When have you felt empowered to be creative in your work at school or job? What facilitates your creativity?
7. What are some blocks to your creativity?

The first question was intended as a manipulation check, i.e. to verify whether or not the participant had been consciously thinking about the fact that their work would be evaluated, or considering what their evaluator would think of their design, as they were completing the design task. Their answers to this question helped us understand if our experimental design worked as intended. In the future, we may also use their responses to this question as a factor in subsequent analyses (e.g., comparing individuals who affirmed that the evaluation/evaluator was on their mind during the task versus those who reported not thinking about it).

When the interview was finished, participants were debriefed on the experiment. They were told the experiment was designed to recreate a moderately stressful situation and that they will not receive feedback from a faculty member or peer. The experimenter answered any questions they had about the aims of the study and thanked them for their time and participation.

**Data Analysis**

*Electrodermal Activity*

The EDA data was preprocessed by applying a low-pass filter (1 Hz) and down sampling the time series from 2000 Hz to 64 to reduce the overall size of each recording. The data corresponding to the Brief period (when participants received the instructions and were told about the feedback and evaluation) and the data corresponding to the Design period (when participants completed the design) were isolated.

Skin potential responses (SPRs) during each of these phases correspond to discrete moments of increased sympathetic nervous system arousal due to reacting to external stimuli (such as receiving instructions) or internal stimuli (effortful thinking, spontaneous thoughts, etc.). The magnitude of SPRs conveys information about the magnitude of arousal due to these internal or external stimuli; thus, averaging the magnitude of SPRs that occur during a given timeframe can be assumed to reflect the average arousal experienced during that time. Thus, the most straightforward way to measure physiological arousal during the brief phase and the design phase is to calculate average SPR responses during those periods.

It is important to note that skin potential responses (SPR) and other measures of electrodermal activity, such as skin conductance responses (SCRs) and tonic skin conductance levels (SCL), reflect physiological arousal driven by the activity of the sympathetic nervous system, and that such activity does not encode information about the valence of the phenomenological experience (i.e., whether it is positive or negative). Increases in physiological arousal may reflect stress, a negative emotion, or excitement, a positive emotion, and thus require interpretation. Because this experiment was intended to induce stress by design, we assume that SPRs that occur during the Brief phase, when participants were told about the problem and that their work would be recorded and evaluated, reflect stress responses (unless any of the participants were particularly masochistic and enjoy being examined and evaluated under pressure). However, SPRs that occur during the Design phase may reflect stress responses from the pressure of coming up with a creative solution or thinking about the evaluation but could also reflect positive arousal related to spontaneous idea generation, i.e., an “aha!” moment. The ambiguity of physiological arousal necessitates corroboration from data sources that can aid their interpretation. In the present study, we use data from the audio and video transcripts during the design phase to determine if strong SPRs reflect a stress response or positive emotional reactions such as an aha moment.

*Power Spectral Density Analysis of Electrodermal Activity*

For frequency domain analysis, the EDA signal was filtered with an $8^{th}$-order Chebyshev type 1 low-pass filter, then decimated by a factor of 10. Then the brief and design periods were separated. Each period was finally filtered by a high-pass $8^{th}$-order Butterworth filter to remove any trends. A Fast Fourier Transform (FFT) with a Blackman window was applied to each period, and the Mean Square Amplitude power spectra were computed and plotted. All signal processing was done using OriginPro 2023 [14].

*Engineering Design Evaluation*

Designs were evaluated for creativity (novelty, appropriateness, fluency, elaboration) by PhD-level mechanical engineering instructors using a rubric, scoring between 1(lowest) to (10) highest along 4 dimensions (appropriateness, novelty, fluency, elaboration). The evaluators independently assessed the designs by looking at the written work product and viewing the recording of the students during the design period. After the independent evaluations were complete, the evaluators discussed their assessments (specifically what struck them about each design) and averaged rubric values.

*Post Interview Coding*

Transcriptions were typed based on listening to a complete account of the post-design interview. To get familiar with the data, the fourth author read and reviewed all transcriptions to understand the gestalt or totality of the responses. This data saturation procedure helps ensure the validity or authenticity of the coding process and reliability or consistency in creating codes that emerge directly from the transcriptions. The transcription passages were then reviewed and formatted into smaller sections using Microsoft word annotation tools like highlighting and boldfacing. The transcription was partitioned into codes using denaturalized transcription that focuses on the basic meaning of the interview [15]. These codes were based on the larger heuristic of creativity and design. Each code represented the basic meaning of each passage. The coding cycle used the principles of Induction, Comparison, Interpretation, and Iteration. Interview quotes representing each code were grouped across transcriptions and summarized below.

**Results and Discussion**

*Representative Time Domain Plot of Skin Potential Level*

Figure 2 is a plot of the electrodermal activity of a representative engineering participant over the duration of the experiment. The first 552s were marked as the Design Brief. The student was at rest and was read the design brief. They were also told that their designs were going to be evaluated for novelty by either their peers or a faculty member during this period. The end of the Design Brief was marked using Biopac's Acqknowledge software. The end of the Design Brief also marks the beginning of the Design Activity. The camera was turned on at this point as well. There are several features of note in the EDA plot. The initial flat signal in the Design Brief is the individual's characteristic Skin Potential Level (SPL). The larger peaks are the biphasic non-specific skin potential responses. These are physiological responses to internal and external stimuli and cannot be interpreted without additional phenomenological (self-reported data).

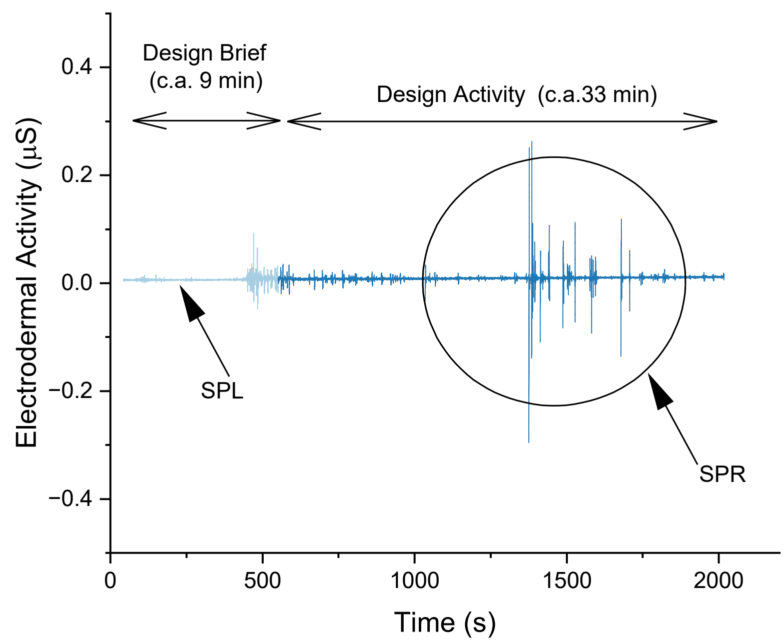


*Figure 4 Representative time domain plot of the EDA signal. The SPL and SPRs are indicated on the plot.*

*Power Spectral Density*

One approach to analyzing EDA data is calculating the Power Spectral Density (PSD) in the frequency domain. The plot in Figure 3 is the mean spectral amplitude power in $\mu S^2$ /Hz of the time domain signal in Figure 2. Quintero et al. report that the 0.045 - 0.15 Hz frequencies are strongly associated with the sympathetic nervous activity (stress) response.  While Shimomura et al. reported that the elevated power in the 0.03-0.5 Hz range is associated with the increased mental workload.  The first plot in Figure 3, labeled Brief Period, is the first 552s of the EDA after applying an FFT algorithm. There is very low power in the frequencies of interest, indicating that this subject was relaxed and listening during the Design Brief.

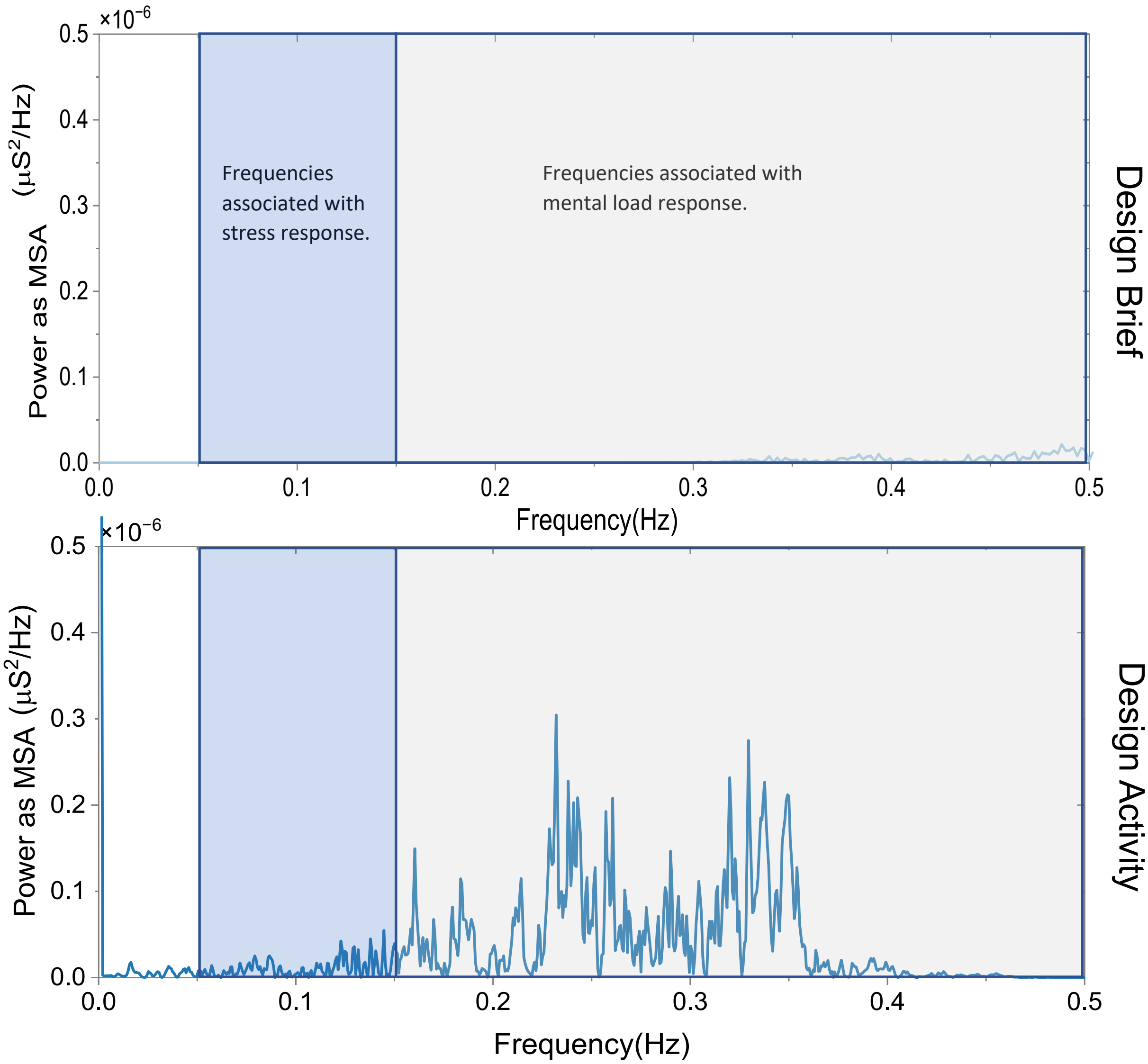


*Figure 5 Plot of the MSA Power in the frequency domain of the (top) Brief Period and (bottom) Design Period of the EDA signal in Figure 2.*

There is a striking difference between the PSD of the Design Brief period and the Design Activity period. The PSD of the Design Brief period shows significant activity in the higher frequencies associated with the mental workload. The participant is actively engaged in the mental work of their design activity, and there is increased activity in the frequencies associated with stress. Future work will include calculating the average power in the two frequency bands to quantify the stress-to-mental activity ratio.

*Average SPRs During Design Brief and Design Activity Periods by Condition (Faculty, Peer)*

To examine whether participants in the faculty condition showed greater evidence of arousal during the brief and design than participants in the peer condition, we compared average SPR responses during the brief and design phases from participants in the faculty condition and the peer condition. As we predicted, we found that average arousal was higher during both the brief and design phases for participants in the faculty condition than the peer condition; however, statistical comparisons were not significant due to the small number of participants in both groups and thus are non-conclusive. This finding was nonetheless reassuring and suggested that expecting an evaluation from a faculty member is more stressful than expecting an evaluation from a peer. This comparison is plotted in Figure 4.

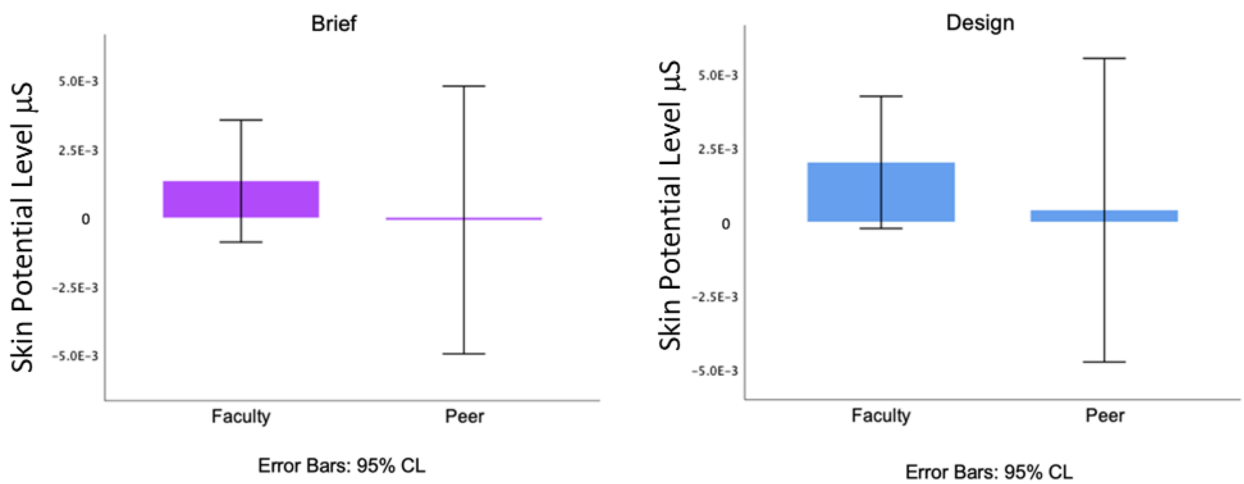


*Figure 6 Comparison of average Skin Potential Level (SPL) of all participants by feedback condition. The error bars are the confidence levels and are very large because of the small sample size; however, we see a trend of higher SPL (more arousal) in the faculty condition.*

*Relationship between Arousal and Design Novelty*

The relationship between physiological arousal and design novelty was examined by correlating the average SPR responses for each participant during the brief and design phases with the novelty score of their final design. We observed a significant negative correlation between arousal and design novelty, suggesting that greater overall arousal during problem-solving may hinder one's ability to develop novel ideas. This relationship is plotted in Figure 5.

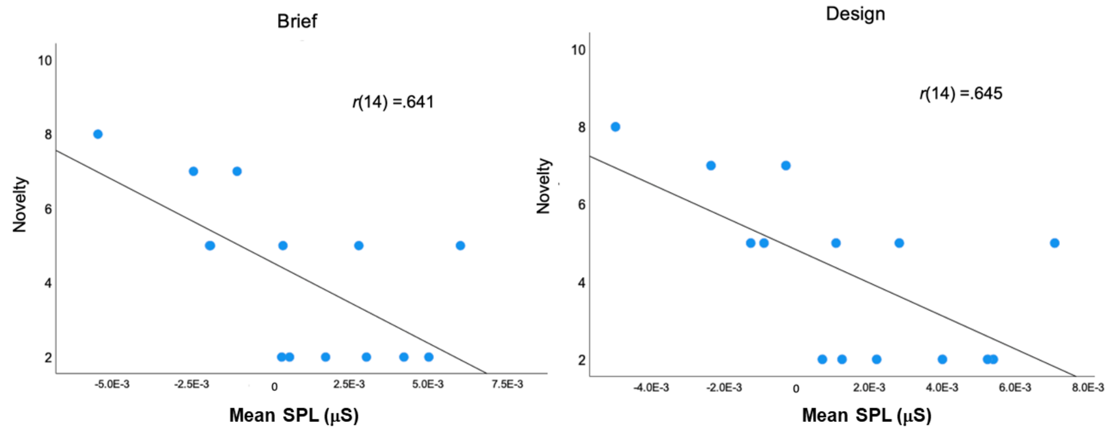


*Figure 7 Relationship between the Skin Potential Level and design novelty assessment. The Pearson coefficient r(14)suggests a negative (inverse) relationship between the average SPL and the novelty of the design. Suggesting stress (higher SPL) does correlate to reduced design novelty. +*

## *Aha! Responses during the Design Phase*

Examination of participant one's EDA signal in Figure 4 shows several large NS-SPRs in the Design Activity period between 1378s and 1394s. When we looked at the recording of the participant's Design Activity period at the same timestamp (NS-SPR 1), we saw and heard them experiencing an "aha!" moment, an insight.

> "…Maybe like a small robot type of thing. **Ooh!**! Like a bookworm. Robotic bookworm so that way, maybe, if you go into like that database. Okay, so we have a monitor next to [it]. This bookshop physical bookshop let's say you input. [sic] Okay, I want this book you'll have a robotic worm that has a BA boom BA boom BA boom moves over just a point I mean, I think you should be able to find the book. So that's me thinking about as a senior in college…"

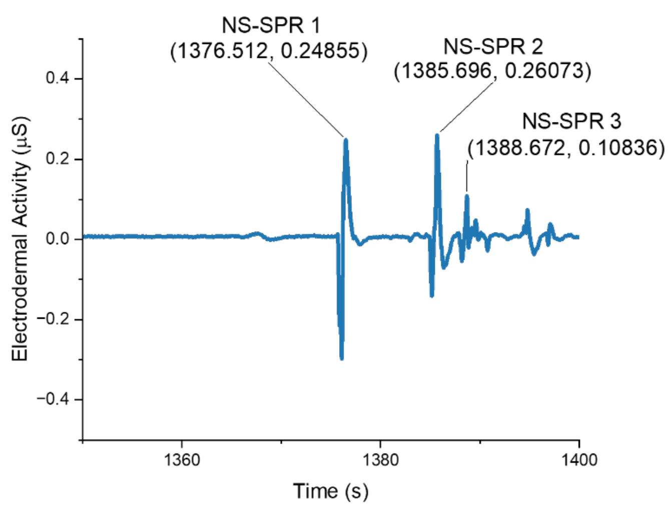


*Figure 8 ROI from Figure 2. NS-SPR1 corresponds to participant 1 expressing an "Aha" moment in their design.*

During problem-solving, aha! moments occur when the solution to a problem (or path to solution) pops into conscious awareness suddenly [17]. “Aha!!!” moments are phenomenologically salient and are associated with feelings of pleasure, surprise, and confidence. Researchers believe that “Aha!!!” moments play a metacognitive role during learning and problem-solving by alerting one to the discovery of a new solution that is fluent, appropriate, and valuable. As a result, “Aha!!!” moments are highly valued in educational contexts. Educators attest that helping students have “Aha!!!” moments is one of the primary goals of instruction, and such moments can be some of the most fulfilling moments in the classroom for both the learner and the teacher [18, 19].

Several studies have found evidence that the subjective experience of insight during problem-solving as well as correctly solving insight-like riddle problems are marked by physiological responses that indicate increased arousal through the involvement of the sympathetic nervous system, including pupil dilation, heart rate, and electrodermal activity (EDA). The sympathetic system is a principal component of emotional experience and, by extension, cognition, and behavior. For example, [20] found greater electrodermal skin conductance responses when participants solved difficult riddle problems that are considered similar to classic “insight tasks” than answering questions about themselves and arithmetic problems. Correctly solving classic “insight” riddle problems has been associated with greater increases in heart rate than solving analytic problems [21,22] also using compound remote associates, found that solving problems with insight was associated with significantly greater skin conductance responses than trials solved analytically [22].

*Design Scores by Academic Background*

Because the pilot participants had a diverse set of backgrounds and majors/minors, we examined whether there were any differences in the overall design score of novelty scores between individuals from different academic disciplines. Among the 16 pilot participants, 2 were engineers, 3 were in the arts/humanities, 6 had business-oriented or political science majors, and 5 studied the sciences (chemistry, biology, psychology). On overall design scores, the engineering students outperformed the rest of the groups (M = 25), and the arts/humanities students scored the lowest (M = 16), while there was no difference between the other groups (M = 19 +/- 1). The same patterns were observed when only considering the novelty scores. This suggests that the engineering students were best prepared to engage in this task, while the arts and humanities students had the least relevant experience. While these patterns make intuitive sense, the low number of participants in each category implies they should only be interpreted as trends.

*Relationship between Affective State, Beliefs about Creativity, and Design Scores*

There was a positive relationship between starting positive mood and overall design scores, $r = 0.342$, and novelty scores, $r = 0.345$, though both relationships were only marginally statistically significant, $p = 0.08$, likely because of the small sample size. This finding is aligned with decades of research on creativity that demonstrates that positive affect improves creativity [16]. We found no relationship between starting negative mood and overall design scores, $r = -0.01$, or novelty scores, $r = 0.09$. The relationship between Beliefs About Creativity [13] and overall design and novelty scores was negative , $r = -0.301$, and $r = -0.199$, respectively, *ns.* The negative relationship between self-beliefs about creative abilities and performance on the creative design task may be driven by discrepancies between the demands of the task and the pilot participants' areas of expertise and domains in which they exercise their creativity. Having noted that arts and humanities majors performed the worst on the task while engineers performed the best, the Beliefs About Creativity Scale may only be relevant when evaluating beliefs about creative ability in the domain that is being assessed in the task. This will be more easily interpretable in the full study (forthcoming) which will only evaluate engineering students.

**Summary of the Student's Interview Responses**

*Adjustable Creativity*

Adjustable creativity emerged as a prominent theme when discussing the impact of instructors and faculty on student creativity. Students' views varied concerning how they adjusted their creativity depending on the salience of potential instructor feedback. To some, instructors did not necessarily encourage creative risk-taking, especially when a project was being graded. In fact, there was a fear of getting things "wrong." Some students indicated that they consciously thought about how they were being evaluated. For example, one student suggested that he thought of a person evaluating him. In turn, this triggered "fleshing" ideas out more to be specific about the design methods and constraints.

Taking creative risks in the presence of instructors was no problem for some. In fact, one student noted that professors "liked more creative projects," indicating that extrinsic motivation was important. Making things "new and original" was an important part of their major. Interestingly, only one student remarked that thinking about the end-user of the product sparked their design creativity. Other students, however, "trusted" their "gut" to be creative and did not necessarily consider the potential of instructor evaluation but instead valued peer feedback more than instructor feedback.

*Peer-Facilitated Creativity*

Evidence from the interviews suggests that peers are incredibly important for student exploration of creative ideas. Additionally, peers appear to have a positive influence on making projects *more* creative. Some students indicated that they generate ideas individually but sometimes preferred building off each other's ideas. One student said:

> I would like to be creative, although I have noticed in the past five years, and with all my co-ops, my biggest strength is kind of building upon other people's ideas you pitch something…. So my friends and I were just meeting constantly figuring just throwing out different ideas that could have some kind of potential.
>
> Other students also credited their friends with supporting their creativity. For example, a student specifically discussed the process of listening to friends to get feedback and

support and then picking the best ideas based on that feedback. Students discussed their networks and friendships easily when describing their creative processes. In addition, they were candid about emotional blocks to creativity.

*Emotional Blocks*

Students acknowledged that being creative is hard and characterized the obstacles that they experienced. This data was more intimate, suggesting insight into the interior lives of students as they negotiate creativity in their mind's eye. Negative emotional states and strong emotional states were considered antithetical to creativity. For example, anxiety, stress, and "overthinking" were cited as a block to creativity. Even though anxiety and bad moods were considered a problem, students also discussed the ability to filter ideas and reflect on them without "shutting them down." This indicated a level of self-reflection and self-awareness in the creative process.

An example of a strong emotional state cited as a potential barrier was "wearing one's heart on the sleeve:" the student referred to the process of keeping herself in check emotionally to be balanced. Other students listed the need for more time and learning aids like visuals to facilitate their creativity. In addition to these issues, a lack of organization and the pressure to develop ideas quickly turned into a block when faced with many new ideas at once. Perfectionism was also mentioned as a barrier to creativity. Relatedly, an overemphasis on logic as a fallacy for inhibiting creativity was discussed as a potential barrier: "I don't feel like creativity is really something that people lean towards anymore, I think that people really lean towards logic and there's nothing wrong with that, but I feel like …My logic actually comes from my creative side."

**Conclusions**

Research on the factors that promote or impede creativity in educational contexts is critical but scarce. The pilot study aimed to explore a multimethod experimental design to capture objective (psychophysiological) together with phenomenological (self-report) measures to capture students' arousal level and subjective experience when engaging in an open-ended creative design task. In addition, we manipulated the expectation of receiving feedback, namely whether students were told that their work would be evaluated either by a faculty or a peer. Our results suggest that anticipating evaluation from a faculty member may result in greater physiological arousal (as measured by EDA response) and can lead to worse creative performance on the design task. The qualitative interviews further elucidated students' experiences engaging in creative problem-solving in learning environments where evaluation is constant. Our interview results show consistent themes that point to ways engineering educators may best support student creativity. We also explored different tools to analyze the electrodermal recordings and showed that the phenomenological data helps to add context to the psychophysiological data, allowing us to interpret the skin potential responses (SCRS) in a natural setting. Overall, the results of this study contribute to our understanding of the influence of arousal and emotions (positive and negative) during naturalistic learning and problem-solving and can be of interest to both engineering design researchers and educators.

## References


[1] C. A. Pradilla, J. B. da Silva, and J. Reinecke, "Wicked Problems and New Ways of Organizing: How Fey Alegria Confronted Changing Manifestations of Poverty," in *Organizing for Societal Grand Challenges*, vol. 79, A. A. Gümüsay, E. Marti, H. Trittin-Ulbrich, and C. Wickert Eds., (Research in the Sociology of Organizations: Emerald Publishing Limited, 2022, pp. 93-114.

[2] W. Mokhtar, "Capstone Senior Project Mentoring And Student Creativity," ed. Atlanta: American Society for Engineering Education-ASEE, 2010, pp. 15.259.1-15.259.16.

[3] A. Gerhart and D. Carpenter, "Creative Problem Solving Course – Student Perceptions Of Creativity And Comparisons Of Creative Problem Solving Methodologies," Pittsburgh, Pennsylvania, 2008. [Online]. Available: https://peer.asee.org/3901.

[4] J. Katz-Buonincontro, O. Davis, A. Aghayere, and D. Rosen, "An exploratory pilot study of student learning experiences in engineering technology courses designed to promote creativity," *Journal of Cognitive Education and Psychology,* vol. 15, pp. 55-79, 2016, doi: 10.1891/1945-8959.15.1.55.

[5] S. R. Daly, E. A. Mosyjowski, and C. M. Seifert, "Teaching Creativity in Engineering Courses," (in English), *Journal of Engineering Education,* vol. 103, no. 3, pp. 417-449, 2014.

[6] M. Agogué, P. Le Masson, C. Dalmasso, O. Houdé, and M. Cassotti, "Resisting classical solutions: The creative mind of industrial designers and engineers," *Psychology of Aesthetics, Creativity, and the Arts,* vol. 9, no. 3, pp. 313-318, 2015.

[7] F. J. Varela, "Neurophenomenology: a methodological remedy for the hard problem," *Journal of consciousness studies,* vol. 3, no. 4, pp. 330-349, 1996.

[8] A. Vásquez-Rosati, R. Montefusco-Siegmund, V. López, and D. Cosmelli, "Emotional influences on cognitive flexibility depend on individual differences: A combined micro-phenomenological and psychophysiological study," *Frontiers in Psychology,* vol. 10, no. MAY, pp. 1138-1138, 2019, doi: 10.3389/fpsyg.2019.01138.

[9] A. Seiryte and E. Rusconi, "The Empathy Quotient (EQ) predicts perceived strength of bodily illusions and illusion-related sensations of pain," *Personality and individual differences,* vol. 77, pp. 112-117, 2015, doi: 10.1016/j.paid.2014.12.048.

[10] E. J. Davelaar, J. M. Barnby, S. Almasi, and V. Eatough, "Differential subjective experiences in learners and non-learners in frontal alpha neurofeedback: Piloting a mixed-method approach," *Frontiers in Human Neuroscience,* vol. 12, pp. 402-402, 2018, doi: 10.3389/fnhum.2018.00402.

[11] A. Jabbari, S. Grimnes, and Ø. G. Martinsen, "Electrodermal response – correlation between potential and conductance," Berlin, Heidelberg, 2007, vol. 17: Springer Berlin Heidelberg, in IFMBE Proceedings, pp. 747-750.

[12] D. Watson, L. A. Clark, and G. Carey, "Positive and Negative Affectivity and Their Relation to Anxiety and Depressive Disorders," *Journal of abnormal psychology (1965),* vol. 97, no. 3, pp. 346-353, 1988, doi: 10.1037/0021-843X.97.3.346.

[13] R. W. Hass, J. Katz-Buonincontro, and R. Reiter-Palmon, "Disentangling Creative Mindsets From Creative Self-Efficacy and Creative Identity: Do People Hold Fixed and Growth Theories of Creativity?," *Psychology of aesthetics, creativity, and the arts,* vol. 10, no. 4, pp. 436-446, 2016.

[14] H. F. Posada-Quintero, J. P. Florian, A. D. Orjuela-cañón, T. Aljama-corrales, S. Charleston-villalobos, and K. H. Chon, "Power Spectral Density Analysis of Electrodermal Activity for Sympathetic Function Assessment," (in English), *Annals of Biomedical Engineering,* vol. 44, no. 10, pp. 3124-3135, 2016.

[15] J. Katz-Buonincontro and A. M. Nezu, *How to interview and conduct focus groups* (Concise guides to conducting behavioral, health, and social science research series). Washington: American Psychological Association, 2022.

[16] Davis, M. A. (2009). Understanding the relationship between mood and creativity: A meta-analysis. *Organizational behavior and human decision processes*, *108*(1), 25-38.

[17] J. Kounios and M. Beeman, "The cognitive neuroscience of insight," *Annual review of psychology,* vol. 65, no. 1, pp. 71-93, 2014, doi: 10.1146/annurev-psych-010213-115154.

[18] B. Czarnocha and W. Baker, *Creativity of an Aha! Moment and Mathematics Education*. Brill/Sense, 2021.

[19] P. G. Liljedahl, "Mathematical discovery and affect: the effect of AHA! experiences on undergraduate mathematics students," *International journal of mathematical education in science and technology,* vol. 36, no. 2-3, pp. 219-234, 2005, doi: 10.1080/00207390412331316997.

[20] J. J. Gross, "The Emerging Field of Emotion Regulation: An Integrative Review," *Review of General Psychology,* vol. 2, no. 3, pp. 271-299, 1998/09/01 1998, doi: 10.1037/1089-2680.2.3.271.

[21] N. Jausovec and K. Bakracevic, "What Can Heart Rate Tell Us About the Creative Process?," *Creativity research journal,* vol. 8, no. 1, pp. 11-24, 1995, doi: 10.1207/s15326934crj0801_2.

[22] W. Shen *et al.*, "Feeling the Insight: Uncovering Somatic Markers of the "aha" Experience," (in English), *Applied Psychophysiology and Biofeedback,* Article vol. 43, p. 13+, 2018.