

## **The investigation of the relationship between emotional engagement and creativity**

### **Dr. Elif Elcin Gunay, Iowa State University**

Elif Elçin Günay received her B.S.E., M.S.E., and Ph.D. degrees in industrial engineering from Sakarya University, Turkey, in 2007, 2009, and 2016 respectively. Her research interest includes optimization, manufacturing systems, supply chain management, engineering education. She is a member of Institute of Industrial Engineers (IIE) and Institute for Operations Research and the Management Sciences (INFORMS).

### **Chih-Yuan Chu, Iowa State University**

Chih-Yuan Chu is a Ph.D. student in the Industrial Engineering program at Iowa State University. His research interests are in data analytics, text mining, and global supply chain risk management.

### **Ms. Liyuani De Jesus Delgado Tapia, Iowa State University**

Liyuani Delgado is a fourth-year industrial engineering student at Iowa State University.

### **Omar ElMenoufy, Iowa State University of Science and Technology**

Industrial engineering undergraduate student with a diverse background of working in high and low volume manufacturing settings, academic research, and technical sales. Skilled in multiple different 2D & 3D design software programs, statistical analysis, and machinery justification and acquisition.

### **Ms. Ani Yam, Iowa State University**

Ani Yam is a junior currently studying Industrial Engineering at Iowa State University. When not busy with her engineering coursework, she dedicates most of her time toward leadership, as the current president of the Iowa State Institute of Industrial Engineers (IISE) chapter and as a student associate and tour guide for the Iowa State Office of Admissions. She got started with ergonomics research with the goal of being able to make an impact on how people look at health in the engineering workplace. Ani hopes to be able to use her experiences and work in the health industry upon graduation while influencing young students to pursue STEM careers.

### **Ms. Shibani Raje, Iowa State University**

Shibani Raje graduated from Iowa State University in May 2020 with a B.S. in Industrial Engineering. She has a background and interest in manufacturing, warehousing, and supply chain management.

### **Dr. Rafal Jonczyk, Adam Mickiewicz University**

Rafał Jończyk (PhD) is an Assistant Professor of Linguistics at the Faculty of English of Adam Mickiewicz University in Poland. His main research interests concern the behavioural and neurocognitive correlates of emotion anticipation, perception, and production in the first (L1) and second (L2) language(s). His recent research interests include the investigation of brain dynamics during creative ideation and the extent to which creative ideation may be modulated by prior knowledge and training.

### **Dr. Danielle S. Dickson, Pennsylvania State University**

Dr. Dickson received a B.S. in Cognitive Science and a B.A. in Linguistics from UC San Diego in 2003. She earned a Ph.D. from the University of Illinois at Urbana-Champaign in 2016 with a dissertation examining the memory system's representation of numerical information, using behavioral and electrophysiological (EEG, brainwaves) measures. She extended this work into comparisons of children and adults' arithmetic processing as a postdoctoral scholar at The University of Texas San Antonio. Presently, she is incorporating more flexible forms of creative thinking as an area of postdoctoral research at Pennsylvania State University to contrast with more fact-based arithmetic numerical comprehension.

**Prof. Janet van Hell, Pennsylvania State University**

Janet van Hell (PhD, University of Amsterdam) is Professor of Psychology and Linguistics and Co-Director of the Center for Language Science at the Pennsylvania State University. She is interested in the neural and cognitive mechanisms underlying language processing in monolingual and bilingual children and adults, including creative language use.

**Prof. Zahed Siddique, University of Oklahoma**

Zahed Siddique is a Professor of Mechanical Engineering at the School of Aerospace and Mechanical Engineering of University of Oklahoma. His research interest include product family design, advanced material and engineering education. He is interested in motivation of engineering students, peer-to-peer learning, flat learning environments, technology assisted engineering education and experiential learning. He is the coordinator of the industry sponsored capstone from at his school and is the advisor of OU's FSAE team.

**Dr. Gül E. Okudan-Kremer, Iowa State University of Science and Technology**

Gül E. Kremer received her PhD from the Department of Engineering Management and Systems Engineering of Missouri University of Science & Technology. Her research interests include multi-criteria decision analysis methods applied to improvement of products and systems. She is a senior member of IIE, a fellow of ASME, a former Fulbright scholar and NRC Faculty Fellow. Her recent research focus includes sustainable product design and enhancing creativity in engineering design settings.

# The investigation of the relationship between emotional engagement and creativity

## Abstract

Background - One of the most critical challenges in engineering education is improving students' divergent thinking skills. Usually, we observe students' fixating on only one single solution for engineering problems. However, their ability to think outside the box and provide alternative solutions should be developed. Research shows that engagement may foster the development of thoughts and boost creativity.

Purpose/Hypothesis – Our aim was to investigate students' engagement with tasks that inspire different facets of creativity (verbal, numeric, and visual). Considering the role of demographics in student engagement, we explored the relationship between their engagement level and demographic traits such as gender, major, age, grades (GPA), and the languages they know besides their native tongue.

Design/Method - We utilized electrodermal activity (EDA) sensors, a well-documented proxy of emotional engagement, to measure students' engagement level while performing tasks that inspire different facets of creativity (verbal, numeric, and visual). Due to the non-normal distribution of the data, non-parametric statistical tests were conducted considering engagement as a dependent variable and demographic traits as independent variables.

Results - Statistically significant differences in students' engagement when exposed to creativity inspired tasks were observed. However, no association between demographics and engagement levels were detected.

Conclusions - The results of the study may support educators in designing the instructional materials considering creativity-inspired activities so that students' engagement level can be increased. Further, results from this study can inform experimental designs, specifically participant selection, in engagement focused studies.

**Keywords:** Electrodermal activity (EDA), gender, demographics

## Introduction

Creativity is a crucial skill for engineers in their education, as they are often faced with complex problems to solve with limited resources and information. As stated by Klukken, Parsons, and Columbus (1997), in an environment that changes rapidly, generating new ideas, alternatives, and innovative solutions is a highly valued skill. In this study, we adopt the definition of creativity as providing original, unique, unconventional, and non-obvious alternatives as opposed to typical ones (Copley, 2016; Guilford, 1950). Because traditional engineering education focuses on training students to solve well-defined, convergent analytical problems (Copley, 2015), students usually struggle to come up with alternative sets of solutions, generate ideas, or fully understand the problem space in more open-ended scenarios. Therefore, a considerable amount of research has focused on tailoring engineering education to enhance students' creative problem-solving skills (e.g., Ogot and Okudan, 2006; Kazerounian and Foley, 2007).

According to the socio-constructivist theory, creativity is linked with emotions in many ways as they can be mediators and products of creative activity (Averill, 2005). Emotions are conceptualized in two dimensions comprised of emotional valence and arousal. Emotional

valence explains the extent to which an emotion is positive or negative, whereas arousal describes the strength of the emotional state (Russell, 2003). Emotional valence play a crucial role in creating. Moreover, when students are engaged — exposed to greater emotional arousal — they are more innovative (Benyahia and Khraisheh, 2014; Prahalad and Ramaswamy, 2003; Oriol et al., 2016). However, more research is needed to understand the underlying mechanisms behind creative ideas and their impact on the generation of emotions (St-Louis & Vallerand 2015). If we can quantify engagement as the attentional and emotional involvement that the student has with the task (Peters, Castellano, and De Freitas, 2009), it may prompt us to understand the association between these two phenomena: engagement and creativity. A way of measuring engagement is through deploying biological sensors. Electrodermal activity (EDA) has been shown to be an objective index of emotional arousal, a state of heightened physiological activity (e.g., joy, excitement), and provides real-time feedback about emotional and cognitive processing. Therefore, many studies utilized EDA sensors to measure the students' engagement level while they were enrolling in different instructional techniques (e.g., Di Lascio, Gashi, and Santini, 2018; Villanueva et al., 2018).

Motivated by research that students learn better and more when they are engaged (Smith, Sheppard, Johnson, and Johnson, 2005), deploying creativity-inspired tasks in the instruction materials can boost their engagement and help students to foster their creativity. Therefore, we focused on the engagement of students while they were performing creativity-inspired tasks. Individuals may reflect a high level of creativity in some domains (e.g., verbal, visual) and lower levels in others (Mourgues et al., 2016). For instance, some individuals are verbally creative and might be more engaged with tasks that require verbal creativity, whereas other students might feel more engaged in numerical activities. There is also evidence of variations in individuals' engagement based on their demographics (Gibson and Slate, 2010). Due to these individual differences, we included a diverse set of tasks that encourage different aspects of creativity, namely verbal, numeric, and visual. In the present study, we measured students' emotional engagement through a wearable EDA sensor (Empatica E4) while students performed three different tasks that are thought to involve creative ideation. Our goal was to understand the impact of these different creativity-inspired tasks on students' engagement and clarify the role that demographic factors might have in engagement. Through understanding the relationship between engagement and creativity-inspired tasks, our research may help educators develop instructional materials that consider different dimensions or facets of creativity to engage students with different interests.

## Background

In the education domain, engagement refers to a student's concentration of attentional, cognitive, and affective education materials (Chen, Lattuca, and Hamilton, 2008). Because of the link between engagement and student's academic success and learning (e.g., Smith et al. 2005), considerable attention is paid to improving student engagement. Studies usually put efforts towards exploring students' engagement across different instructional methods. In these studies, self-reported surveys (e.g., Gonyea, 2005; Frenslay et al., 2020) were primarily used to collect data about student's engagement levels. Thanks to technological advancements, researchers can now monitor the physiological signatures of cognitive arousal instead of relying only on self-report measures. Electroencephalogram (EEG) (e.g., Fink and Benedek, 2014), functional magnetic resonance imaging (fMRI) (e.g., Fink et al., 2009), heart rate monitoring (e.g., Mehler et al., 2009), eye tracking (e.g., Palinko et al. 2010), facial expressions (e.g., Lisetti and Schiano,

2000), and EDA sensors (e.g., Braithwaite et al., 2013) are all now used. Due to its convenience in terms of cost and ease of use, and its reliability in measuring emotional and physiological arousal, the EDA sensor is a frequently utilized alternative. For example, Di Lascio et al. (2018) deployed EDA sensors to measure students' emotional engagement during lectures unobtrusively. Likewise, Villanueva et al. (2018) investigated the effects of EDA in different instructional delivery formats, i.e., hands-on activities vs. generic lecture learning environment. Both studies reported that students' engagement levels were increased when active learning strategies were implemented. Kim (2018) developed an intelligent system that collects students' engagement levels through EDA and informs the instructor about the class's engagement level. Thus, the instructor was able to change the instructional delivery method to attract students' engagement. Khan, Villanueva, Vicioso, and Husman (2019) utilized temperature and EDA sensors during engineering exams. They claimed that there was a weak positive correlation between questions' difficulty index, EDA, and temperature. Morrison, Rozak, Gold, and Kay (2020) used EDA as an index of student's engagement in climate change learning through active learning strategies in higher education. The study verified that the EDA data matched with self-reported engagement survey results. Together these results confirm that the EDA is a robust proxy for engagement.

Creative ideation and its associated cognitive processes are yet to be characterized and understood, with relatively few neurocognitive studies covering this area of research (Fink & Benedek, 2014). Studies have varied methodologically (using different techniques to measure biological signals such as brain activity) and experimentally (using different tasks and operational definitions of "creativity"). For instance, Kraus, Cadle, and Simon-Dack (2019) used EEG to measure the electrical activity in participants' brains during an Alternative Uses Task (AUT). The results of this test showed that generated uses for the AUT become more creative over time, whereas the fluency of the responses decreases. This result aligns with a study conducted by Zabelina and Ganis (2018), who explored the relationship between cognitive control and creativity. Event-related potentials (ERPs), EEG, and fMRI scans were used to examine how divergent thinking and creative achievement were linked to cognitive control and flexibility. An adapted version of the Local-Global letter task was used, where participants had to find a target letter out of a diagram of other letters. The authors reported that divergent thinkers had higher levels of attentional flexibility and were more strongly engaged. However, they also found that creative achievement did not significantly impact either flexibility or engagement. In work utilizing other techniques, Muldner and Burleson (2015) used an eye tracker, a skin conductance bracelet, and an EEG sensor while students were generating geometry proofs (a creativity related task). The objective of the study was to differentiate low and high creativity students. The authors reported that their low-creativity group showed shorter normalized saccade length and had higher overall short-term excitement according to EEG data. Nevertheless, no skin conductance difference between low and high creativity groups was observed.

As the above review of the empirical literature shows, studies on creativity either focused on the techniques that were used to measure biological signals (e.g., EEG) or the behavioral tasks/activities the participants performed (creativity assessment techniques). The impact of students' engagement on creativity-required tasks has not been examined. However, research shows that when students are engaged with the activity, they are more innovative (Oriol et al., 2016). Driven by two phenomena, (i) students learn better and more when engaged, and (ii) engaged students are more creative, our study contributes to the literature by understanding the emotional aspect of creativity. Thus, it may help educators to develop instructional materials that

foster student's engagement. Note that our intent is not to measure the creativity level of the students; instead, we aim to understand how their engagement is impacted by creativity-inspired tasks. The benefit of the research to the community includes promoting students' learning and increasing students' creativity, since course materials can be designed to inspire creativity.

## **Methodology**

### **Participants**

Twenty-eight Iowa State University students (15 females, 13 males; age range: 18-29) volunteered to take part in the study. All participants had normal or corrected-to-normal vision and hearing acuity. None had a history of movement disorders or problems using response devices, and none were under the influence of any drugs or substances. These students were recruited from a variety of engineering disciplines, including chemical engineering (2), civil engineering (3), computer engineering (2), electrical engineering (4), industrial engineering (13), materials science (1), mechanical engineering (2), and software engineering (1). In addition, these participants were distributed among freshmen (5), sophomores (1), juniors (4), seniors (12), and graduate students (6). All participants were informed about the purpose and duration of the experiment and signed a consent form before the experiment started.

### **Materials**

The literature shows different methods for creativity assessment depending on the definition of the creativity, e.g. geometry proof generation (Muldner and Burleson, 2015), gambling (Galang et al., 2016), or well-documented tests such as the AUT or the utopian situation task. In this study, we focused on originality, uniqueness, unconventionality, and non-obvious alternatives in the context of verbal, numeric, and visual creative problem-solving. Therefore, our experiment included a total of eight questions in the following categories: (i) puzzle-like questions (verbal facet, e.g., find five red things that will fit in your pockets), (ii) mental rotation activities with common 2-D shapes (visual facet), and (iii) numeric calculations (numeric, e.g., find the sum of your date of birth). Stimuli presentation was controlled by the Presentation software (Neurobehavioral Systems, Inc.). The list of experimental materials is presented in the Appendix.

### **Data collection**

Every participant was asked a series of survey questions on Qualtrics. These questions collected demographic data concerning participants' gender, major, age, grades, and fluency in any other language besides their native tongue. Having completed the survey, each participant was introduced to the EDA system Empatica E4, which was placed on their non-dominant hand. A baseline EDA level was recorded during 15 minutes of rest (i.e., the baseline period). In the experiment, participants viewed questions presented on a screen and were asked to reply to each question out loud. They were also informed that their responses were not being recorded or collected for further analyses. An administrator stayed in the room to report any arm movements that may contaminate EDA recordings. The entire data collection procedure, including the survey, the baseline recording and the main recording, lasted 35 minutes. This study was run over the course of four weeks with five different administrators.

EDA levels vary across individuals, due to the level of sweat glands and electrical conductivity levels. Thus, a standardized EDA was found to compare levels across participants to eliminate within-subject variation. Below, Equation (1) shows the standardization formula.

$$z_{ik} = \frac{X_{ik} - \bar{x}_i}{s_i} \quad (1)$$

where  $X_{ik}$  is the raw score and  $z_{ik}$  the standard value (z-score) of  $EDA_k$  for individual  $i$ . The notations  $\bar{x}_i$  and  $s_i$  are the mean and standard deviation, respectively, for all EDA recordings of individual  $i$ .

## Results and Discussion

Since Anderson-Darling normality test failed to reach significance, we proceeded with non-parametric tests. Wilcoxon signed-rank test confirmed that there was a significant EDA difference for the experiment and baseline period ( $Z=-4.228, p < .000$ ). As seen in Figure 1, the EDA for the experiment is more pronounced than that for the baseline period. This result shows that the experiment engaged students, leading to an increase in the EDA.

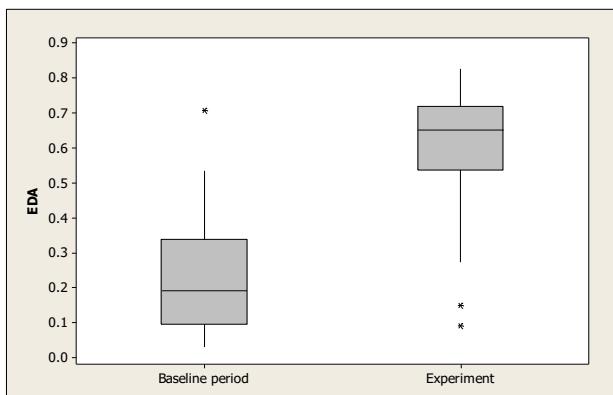


Figure 1. EDA levels for the baseline period and experiment

We conducted Wilcoxon rank-sum tests considering students' demographics (gender, major, age, grades, multilingualism) as the independent variables and EDA as the dependent variable. The null hypotheses for these tests were that the median difference in EDA for different gender, major, age, grades, and multilingualism was zero, respectively. This would entail that students' EDA is not modulated by their demographic profile. The alternative hypothesis corresponded to the case when the median difference in EDA for different gender, major, age, grades multilingualism was not zero. The following sub-sections discuss our findings.

### a) Gender Effect

As discussed in the introduction, some previous studies tested the effect of gender on students' engagement, but the results are inconclusive. For example, Annetta et al. (2009) suggested that the engagement level of the students does not depend on their gender. Likewise, Adolsky (2019) found that there were no gender-based differences in EDA during cognitive workload related tasks. Examples of these cognitive tasks included mathematical calculations, where the test subject was asked to subtract two numbers from each other, as well as visual tasks, like looking at a picture for a short period of time. Contrary to these findings, Kinzie et al. (2007) showed that females were more engaged in academic activities, while Hu and Wolniak (2013) demonstrated that males were more engaged academically. The differences in these findings may

be attributed to differences in the tasks as well as in the characteristics of the participant samples. To gain more insight into the impact of gender on students' engagement during creative problem solving, we compared male and female students' EDA recordings. In our analysis, according to the Wilcoxon Rank Sum test and box-plot graph in Figure 2, there was no significant EDA difference during the experiment between female and male students ( $W=190$ ,  $Z= -.291$ ,  $p=.793$ )

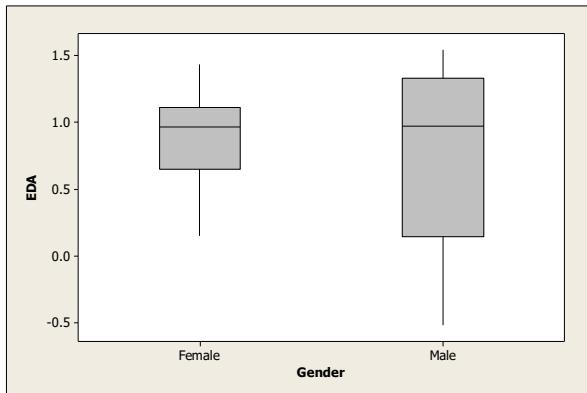


Figure 2. EDA for different gender groups

### b) Major (program of study) effect

As different majors have different interests, students' majors might affect students' engagement levels when they approach a task. To divide our participants into different groups, we used the Holland Classification Theory (Holland 1997). In Holland's Classification Theory, individuals can be split into different categories of careers based on their personality traits and interests (realistic, investigative, artistic, social, enterprising, and conventional) that influence their career choice. For example, electrical and mechanical engineering fall into realistic groups, while chemical and civil engineers are categorized as investigative groups. According to Holland's Classification Theory, individuals are assumed to pursue their career according to their motivation, personality, and abilities (Lattuca, Terenzini, Harper, and Yin, 2009). Hence, variation in students' motivation, interest maybe different across different engineering disciplines. In our analysis, majors were assigned to the following groups upon Holland's Theory (Holland, 1997). Group 1 were the realistic majors (electrical and mechanical), group 2 were the investigative majors (aerospace, chemical, materials, and civil), and group 3 were the enterprising majors (industrial, computer, and software).

We expected our results to vary across the three groups. However, Kruskal-Wallis test indicated no significant EDA difference during the experiment for different engineering majors ( $\chi^2(2)=4.146$ ,  $p=.126$ ). Figure 3 demonstrates the box-plot of EDA for three major groups. Pike, Smart, and Ethington (2012) assessed the engagement level of different STEM majors, according to Holland's theory considering various educational activities. The findings showed that investigative disciplines were more engaged with higher-order thinking activities than enterprising majors; however, no difference between investigative and social majors was observed. Students in social environments presented higher engagement in collaborative learning than investigative and artistic disciplines. The difference between their study and ours might be due to the type of engagement. Pike et al. (2012) focused on the cognitive aspect of engagement while we focused on the emotional aspect. Additionally, our experiment was only limited to

engineering students; no other STEM disciplines were included. Extending the sample through including students from different STEM fields may be a future avenue of research.

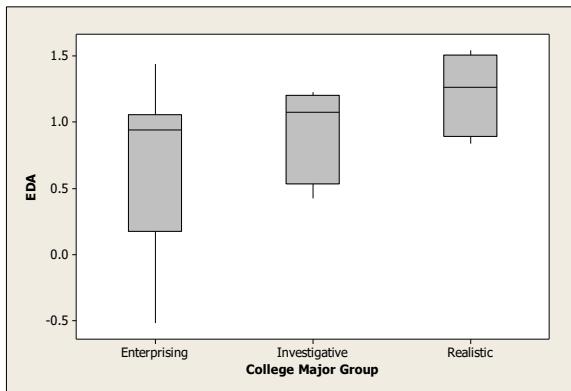


Figure 3. EDA for different major groups

### c) Age effect

Creativity has been correlated with age in previous studies (e.g., Zhang, 1999). Therefore, age differences across participants were thought to impact participants' engagement with creativity-inspired tasks. The age of 21 years was chosen as the threshold for dividing the sample into two groups in order to obtain almost an even number of participants in each group. Additionally, in our analysis, students who were above 21 years old were senior and graduate students. Since senior and graduate students were more trained for creativity during their engineering education, we expected them to feel more engaged with the experiment. Specifically, Bruce, Omne-Pontén, and Gustavsson (2010) observed that the emotional engagement of nursing students increased during three-year education. Likewise, Gibson and Slate (2010) compared the engagement level of freshmen aged 24 and below (traditional-age students) and ages 25 and above (nontraditional-age students). They found a significant impact of age on student engagement levels. However, in our analysis, according to the Wilcoxon Rank Sum test, age did not appear to have a significant impact on EDA ( $W=182$ ,  $Z=.000$ ,  $p=1.000$ ). This might be due to the narrow age range of our participants, which reduced the likelihood to observe an age effect. The box-plot graph of EDA for age groups is presented in Figure 4.

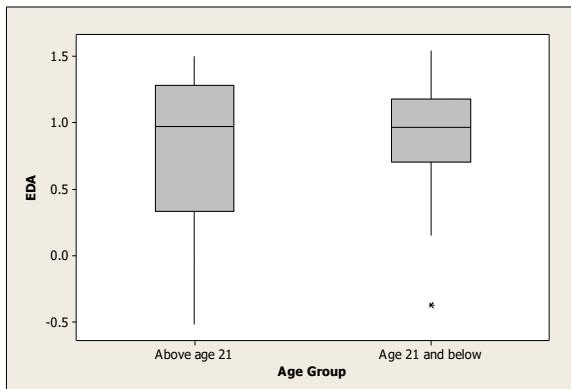


Figure 4. EDA for age groups

### e) Grades effect

Research about the impact of grades on creativity is inconclusive. While Altman (1999) reported a significant relationship between grade point average and creativity, other studies (e.g., Ai, 1999) were not able to establish a link between these two factors. In our analysis, students were assigned into three groups according to their grades. Group 1 included the students with a GPA between 2.00 and 2.99. Students with a GPA between 3.00 and 3.49 were assigned to group 2, and students with a GPA between 3.50 and 4.00 were included in group 3. The box-plot of EDA for different grade groups is shown in Figure 5. According to the Kruskal-Wallis test, there was no significant EDA difference during the experiment for GPA ( $\chi^2(2)=2.206, p=.332$ ). This finding contrasts with Melius et al. (2010) who showed a positive correlation between student engagement and academic achievement. To compare groups with different engagement levels, they measured students in collaborative learning and lecture style classes with surveys. The varying results between Melius et al.'s (2010) study and our study could be due to the difference in testing environments. We looked at the EDA levels of students during their responses to verbal cognitive questions, while Melius et al. examined students' engagement during a lecture class. Further, the participants in Melius et al. (2010) only enrolled in lectures, whereas our participants were asked to interpret a question and provide a response in return. Another reason for the difference in results may relate to the nature of the collected data. While Melius et al. (2010) explored the relationship between EDA levels and the students' grades from that class, we did not grade the responses to the test questions that we used in our study and only used the test subject's cumulative GPA in school. Because students' GPA cannot fully reflect students' performance in the test, we might not be able to find a significant difference in this factor.

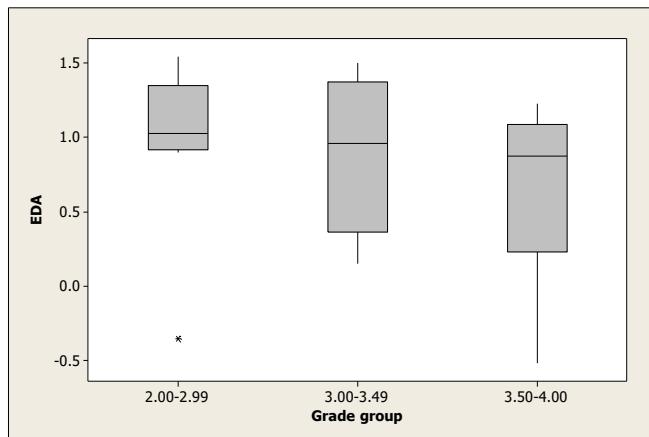


Figure 5. EDA for grade groups

### f) Multilingualism effect

For years, the cognitive control of multilingual individuals has been studied, driving to a substantial body of evidence that supports better performance of multilinguals relative to monolinguals during cognitive tasks, although an increasing number of studies did not find such a multilingual advantage (for a recent review, see Antoniou, 2019). Studies performed on multilingual children suggested that switching between languages may help individuals practice cognitive control, which is understood as a skill that builds up over time, and that provides them an advantage in controlling attention (for a recent review, see Poarch & Van Hell, 2018).

Therefore, we examined whether multilingualism had a significant impact on the engagement of engineering students based on creativity-inspired tasks. We considered the participants who reported being “fluent” in at least one language other than English as multilinguals according to their self-assessments. From our sample, nine participants fulfilled this criterion. For four of them, this language was their first language, while the rest said that the language is their  $n^{\text{th}}$  language. Wilcoxon Rank Sum test results failed to reach significance for the multilingualism effect ( $W=264$ ,  $Z=-.885$ ,  $p=.400$ ). Thus, there was no difference in the students’ engagement level who were not fluent in a language other than English (monolingual) and fluent in a language other than English (multilingual), see box-plot in Figure 6. However, Raj et al. (2019) reported that students who spoke multiple languages were more engaged and were more likely to succeed in a computer science programming course. Several factors could have impacted the different result pattern in our study and Raj et al. (2019), including a limited range of college majors (computer science) and the scope of their study.

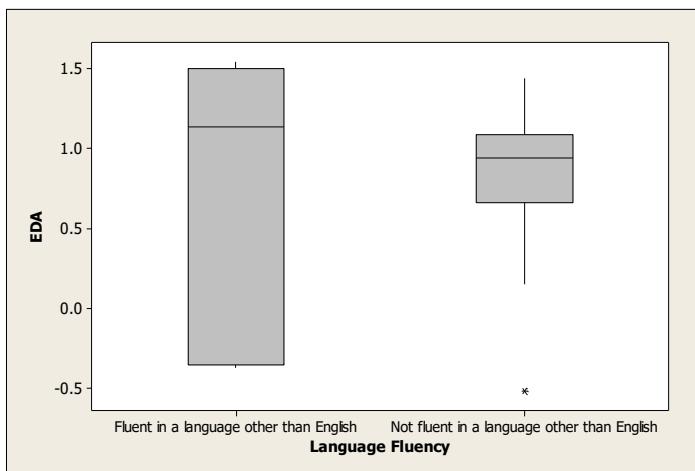


Figure 6. EDA for language fluency

## Conclusion

The objective of the study was to assess the engagement level of students while they were participating in creativity-inspired tasks. Building on the research that emphasizes the importance of engagement in creativity and student learning, we aimed to quantify student engagement as an attentional and emotional involvement with the creativity-inspired tasks. To attract a broad range of students, we generated questions that reflect the verbal, numeric, and visual facets of creativity. Our results showed that the EDA of the students during the experiment was above their EDA while they were resting. From this, we interpret that the experiment was successful in engaging students. Our findings may assist educators to enrich their instructional materials considering the variations in students’ motivations. Therefore, questions that challenge students from different perspectives of creativity (verbal, numeric, visual) can help engage students. Because of the previously reported impact of demographic traits on engagement, we further examined whether there were any differences across students based on gender, major, age, grades, and other languages spoken besides their native language. However, no significant relationship between independent variables (gender, major, age, grades, and multilingualism) and emotional engagement was observed. We hope that future studies will analyze the impact of

question type (verbal, numeric, visual) and its association with students' demographic traits to better understand their role in student engagement.

## References

Ai, X. (1999). Creativity and academic achievement: An investigation of gender differences. *Creativity Research Journal*, 12(4), 329-337.

Aldosky, H. Y. (2019). Impact of obesity and gender differences on electrodermal activities. *General Physiology and Biophysics*, 38(6), 513-518.

Altman, W. S. (1999). Creativity and academic success. *Dissertation Abstracts International Section A. Humanities and Social Sciences*, 59(10A), 3731.

Annetta, L., Mangrum, J., Holmes, S., Collazo, K., & Cheng, M. T. (2009). Bridging reality to virtual reality: Investigating gender effect and student engagement on learning through video game play in an elementary school classroom. *International Journal of Science Education*, 31(8), 1091-1113.

Antoniou, M. (2019). The advantages of bilingualism debate. *Annual Review of Linguistics*, 5, 395-415.

Averill, J. R. (2005). Emotions as mediators and as products of creative activity. *Creativity across Domains: Faces of the Muse*, 225-243.

Benyahia, F., & Khraishehla, M. (2014, March). Innovation and creativity in engineering design: The role of student engagement, team spirit and industry support. In *Fourth Interdisciplinary Engineering Design Education Conference* (pp. 52-57). IEEE.

Braithwaite, J. J., Watson, D. G., Jones, R., & Rowe, M. (2013). A guide for analysing electrodermal activity (EDA) & skin conductance responses (SCRs) for psychological experiments. *Psychophysiology*, 49(1), 1017-1034.

Bruce, M., Omne-Pontén, M., & Gustavsson, P. J. (2010). Active and emotional student engagement: A nationwide, prospective, longitudinal study of Swedish nursing students. *International Journal of Nursing Education Scholarship*, 7(1), 1-18.

Chen, H. L., Lattuca, L. R., & Hamilton, E. R. (2008). Conceptualizing engagement: Contributions of faculty to student engagement in engineering. *Journal of Engineering Education*, 97(3), 339-353.

Cropley, D. H. (2015). Promoting creativity and innovation in engineering education. *Psychology of Aesthetics, Creativity, and the Arts*, 9(2), 161-171.

Cropley, D. H. (2016). Creativity in engineering. In *Multidisciplinary contributions to the science of creative thinking* (pp. 155-173). Springer, Singapore.

Di Lascio, E., Gashi, S., & Santini, S. (2018). Unobtrusive assessment of students' emotional engagement during lectures using electrodermal activity sensors. *Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies*, 2(3), 1-21.

Fink, A., & Benedek, M. (2014). EEG alpha power and creative ideation. *Neuroscience & Biobehavioral Reviews*, 44, 111-123.

Fink, A., Grabner, R. H., Benedek, M., Reishofer, G., Hauswirth, V., Fally, M., ... & Neubauer, A. C. (2009). The creative brain: Investigation of brain activity during creative problem solving by means of EEG and fMRI. *Human Brain Mapping*, 30(3), 734-748.

Frensley, Troy, B., Stern, M. J., & Powell, R. B. (2020). Does student enthusiasm equal learning? The mismatch between observed and self-reported student engagement and environmental literacy outcomes in a residential setting. *The Journal of Environmental Education*, 1-12.

Galang, A. J. R., Castelo, V. L. C., Santos III, L. C., Perlas, C. M. C., & Angeles, M. A. B. (2016). Investigating the prosocial psychopath model of the creative personality: Evidence from traits and psychophysiology. *Personality and Individual Differences*, 100, 28-36.

Gibson, A. M., & Slate, J. R. (2010). Student engagement at two-year institutions: Age and generational status differences. *Community College Journal of Research and Practice*, 34(5), 371-385.

Gonyea, R. M. (2005). Self-reported data in institutional research: Review and recommendations. *New directions for institutional research*, 2005(127), 73-89.

Guilford, J., (1950) Creativity, *American Psychology*, 5, 444-454.

Holland, J. L. (1997). *Making vocational choices: A theory of vocational personalities and work environments*. Psychological Assessment Resources.

Hu, S., & Wolniak, G. C. (2013). College student engagement and early career earnings: Differences by gender, race/ethnicity, and academic preparation. *The Review of Higher Education*, 36(2), 211-233.

Kazerounian, K., & Foley, S. (2007). Barriers to creativity in engineering education: A study of instructors and students perceptions. *International Design Engineering Technical Conferences & Computers and Information in Engineering Conference*.

Khan, T. H., Villanueva, I., Vicioso, P., & Husman, J. (2019). Exploring relationships between electrodermal activity, skin temperature, and performance during. *IEEE Frontiers in Education Conference (FIE)* (pp. 1-5). IEEE.

Kim, P. W. (2018). Real-time bio-signal-processing of students based on an Intelligent algorithm for Internet of Things to assess engagement levels in a classroom. *Future Generation Computer Systems*, 86, 716-722.

Kinzie, J., Gonyea, R., Kuh, G. D., Umbach, P., Blaich, C., & Korkmaz, A. (2007, November). The relationship between gender and student engagement in college. Association for the Study of Higher Education Annual Conference.

Klukken, Gary P., J. Roger Parsons, and Peter J. Columbus. (1997). The Creative Experience in Engineering Practice: Implications for Engineering Education. *Journal of Engineering Education*, 86(2), 133-138.

Kraus, B., Cadle, C., & Simon-Dack, S. (2019). EEG alpha activity is moderated by the serial order effect during divergent thinking. *Biological psychology*, 145, 84-95.

Lattuca, L. R., Terenzini, P. T., Harper, B. J., & Yin, A. C. (2010). Academic environments in detail: Holland's theory at the subdiscipline level. *Research in Higher Education*, 51(1), 21-39.

Lisetti, C. L., & Schiano, D. J. (2000). Automatic facial expression interpretation: Where human-computer interaction, artificial intelligence and cognitive science intersect. *Pragmatics & cognition*, 8(1), 185-235.

Mehler, B., Reimer, B., Coughlin, J. F., & Dusek, J. A. (2009). Impact of incremental increases in cognitive workload on physiological arousal and performance in young adult drivers. *Transportation Research Record*, 2138(1), 6-12.

Melius, J. (2010). Student Engagement As a Factor in Academic Achievement: The Case of Undergraduates at Norfolk State University, Virginia.  
[http://web.a.ebscohost.com/ehost/ebookviewer/ebook/ZTAwMHhuYV9fNDkyODIx19BTg2?s\\_id=66db3073-1f6a-4a48-9cb4-88a8a8c569c8@sdc-v-sessmgr01&vid=0&format=EB&lpid=lp\\_111&rid=0](http://web.a.ebscohost.com/ehost/ebookviewer/ebook/ZTAwMHhuYV9fNDkyODIx19BTg2?s_id=66db3073-1f6a-4a48-9cb4-88a8a8c569c8@sdc-v-sessmgr01&vid=0&format=EB&lpid=lp_111&rid=0)

Morrison, A. L., Rozak, S., Gold, A. U., & Kay, J. E. (2020). Quantifying student engagement in learning about climate change using galvanic hand sensors in a controlled educational setting. *Climatic Change*, 159(1), 17-36.

Morton, J., & Harper, S. (2007). What did Simon say? Revisiting the bilingual advantage. *Developmental Science*, 10(6), 719-726.

Mourgues, C., Tan, M., Hein, S., Elliott, J. G., & Grigorenko, E. L. (2016). Using creativity to predict future academic performance: An application of Aurora's five subtests for creativity. *Learning and Individual Differences*, 51, 378-386.

Muldner, K., & Burleson, W. (2015). Utilizing sensor data to model students' creativity in a digital environment. *Computers in Human Behavior*, 42, 127-137.

Ogot, M., & Okudan, G. E. (2006). Systematic creativity methods in engineering education: A learning styles perspective. *International Journal of Engineering Education*, 22(3), 566-576.

Oriol, X., Amutio, A., Mendoza, M., Da Costa, S., & Miranda, R. (2016). Emotional creativity as predictor of intrinsic motivation and academic engagement in university students: the mediating role of positive emotions. *Frontiers in psychology*, 7, 1243.

Palinko, O., Kun, A. L., Shyrokov, A., & Heeman, P. (2010). Estimating cognitive load using remote eye tracking in a driving simulator. In *Proceedings of the 2010 symposium on eye-tracking research & applications*, 141-144.

Peters, C., Castellano, G., & De Freitas, S. (2009). An exploration of user engagement in HCI. In *Proceedings of the International Workshop on Affective-Aware Virtual Agents and Social Robots*.

Pike, G. R., Smart, J. C., & Ethington, C. A. (2012). The mediating effects of student engagement on the relationships between academic disciplines and learning outcomes: An extension of Holland's theory. *Research in Higher Education*, 53(5), 550-575.

Poarch, G., & Van Hell, J. G. (2018). Bilingualism and the development of executive function in children – the interplay of language and cognition. In: S. A. Wiebe and J. Karbach (Eds.), *Executive function: Development across the lifespan* (pp. 172-187). New York, Routledge.

Prahalad, C. K., & Ramaswamy, V. (2003). The new frontier of experience innovation. *MIT Sloan Management Review*, 44(4), 12.

Raj, A. G. S., Zhang, H., Abhyankar, V., Mukerjee, S., Zhang, E., Williams, J., ... & Patel, J. M. (2019, November). Impact of Bilingual CS Education on Student Learning and Engagement in a Data Structures Course. In *Proceedings of the 19th Koli Calling International Conference on Computing Education Research* (pp. 1-10).

Russell, J. A. (2003). Core affect and the psychological construction of emotion. *Psychological review*, 110(1), 145.

Smith, K. A., Sheppard, S. D., Johnson, D. W., & Johnson, R. T. (2005). Pedagogies of engagement: Classroom-based practices. *Journal of Engineering Education*, 94(1), 87-101.

St-Louis, A. C., & Vallerand, R. J. (2015). A successful creative process: The role of passion and emotions. *Creativity Research Journal*, 27(2), 175-187.

Villanueva, I., Campbell, B. D., Raikes, A. C., Jones, S. H., & Putney, L. G. (2018). A multimodal exploration of engineering students' emotions and electrodermal activity in design activities. *Journal of Engineering Education*, 107(3), 414-441.

Zabelina, D. L., & Ganis, G. (2018). Creativity and cognitive control: Behavioral and ERP evidence that divergent thinking, but not real-life creative achievement, relates to better cognitive control. *Neuropsychologia*, 118, 20-28.

Zhang, L. F. (1999). Further cross-cultural validation of the theory of mental self-government. *The Journal of Psychology*, 133(2), 165-181.

## Appendix

Number	Question
1	Say the days of the week backward, then in alphabetical order.
2	Say the months of the year in alphabetical order.
3	Find the sum of your date of birth (m+m+d+d+y+y+y+y).
4	Name two objects that start with the same letter as each letter in your first name.
5	Look around wherever you are, and try to find 5 red things that will fit in your pockets and 5 blue objects that are too big to fit in.
6	Name 5 objects from your bedroom.
7	You will see a matrix in this question, and you are required to decide whether it is a normal or reversed number, as in this example: <div style="text-align: center;"> <span style="font-size: 2em;">4</span> (normal) <span style="font-size: 2em;">4</span> (reversed)          (Please don't rotate your device or your head!)         <div style="margin-top: 10px; text-align: center;"> <span style="font-size: 1.5em;">L</span> <span style="font-size: 1.5em;">↗</span> <span style="font-size: 1.5em;">2</span>  <span style="font-size: 1.5em;">2</span> <span style="font-size: 1.5em;">↙</span> <span style="font-size: 1.5em;">✓</span>  <span style="font-size: 1.5em;">↖</span> <span style="font-size: 1.5em;">1</span> <span style="font-size: 1.5em;">↖</span> </div> </div> <p>Please go from left to right for each row:</p>
8	Spot 5 differences between the two pictures: 