Correlating the student engineer's design process with emotional intelligence.

Dr. Ryan H Koontz, South Dakota School of Mines and Technology

Ryan Koontz received his Bachelor's degree in Mechanical Engineering in 1999 and an M.S. degree in mechanical engineering in 2002 from the South Dakota School of Mines and Technology (SDSMT). In 2004, Ryan joined the Center of Excellence for Advanced Multi-Disciplinary Projects (CAMP) as the manufacturing specialist. He currently instructs students of CAMP through the design and manufacturing process and helps produce parts for the co-curricular teams of CAMP. He completed in 2017 his Ph.D. in Mechanical Engineering at SDSMT, focusing on student development and design thinking.

Dr. Daniel F Dolan, South Dakota School of Mines and Technology

Dr. Dolan joined the South Dakota School of Mines and Technology Mechanical Engineering Department in 1981. In 1997 he was instrumental in forming CAMP, now the Center for Advanced Multidisciplinary Projects, which he directs.

Kimberly Karen Osberg, The Center of Excellence of Advanced Multi-disciplinary Projects, SDSM&T

Kimberly Osberg, Associate Director for the Center for Advanced Multi-disciplinary Projects (CAMP). Kim earned her B.S. from South Dakota State University in 1995 and is pursuing her M.S. from USD as well. Kim has spent much of her post graduate work in the area of Student Development, Leadership and Emotional Intelligence.

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The design process is a set of steps that an engineer must follow to complete a successful design. This process is a fundamental aspect of engineering education and includes actions such as defining the problem, specifying requirements, and brainstorming solutions within specific criteria. In the classroom or capstone design, an educator often requires students to brainstorm several possible solutions for each design challenge before proceeding to the next step of the design process. Even though many educators encourage their students to formulate three to five solutions before moving forward with the process, this research and other compelling studies [1], [2], [3], reveals that most engineering students construct fewer than two possible solutions (~1.3) before selecting one and completing the design with that solution.

Although students are taught that the brainstorming step, the creative process whereby several possible solutions are determined before proceeding, is an essential aspect of engineering design, they are failing to spend adequate time and energy on this part of the process. Instead of brainstorming several solutions when given an open-ended design problem, they simply proceed in designing the first possible solution that comes to mind. Our research reveals a possible connection between how an individual tackles an open-ended design problem and their emotional intelligence scores. Although we cannot imply cause and effect, we should not overlook findings showing a social-emotional connection to the process of design.

We believe that part of the answer to this design dilemma may be found in how the individual processes the challenge through their level of emotional intelligence. As such, the purpose of this study is to examine the relationship between trait emotional intelligence and an engineering student's cognitive design process. Emotional intelligence (EI) is the capability of individuals to recognize their own and other people's emotions and to use emotional information to guide thinking and behavior [4].

For this research, an emotional intelligence assessment was administered to each participant. This evaluation generates 21 scores measuring trait emotional intelligence. A verbal protocol analysis was used to document the design process of each participant. Each student was asked to solve a design problem in a *think-aloud* manner. The transcripts of these design sessions are segmented and coded with a predetermined coding scheme developed by Atman and Adams [2], [3], [5]. Design variables generated from the coded transcripts are used to compare the design process with the emotional intelligence scores.

Most descriptions of emotional-social intelligence include one or more of these components:

> *a) the ability to recognize, understand and express emotions and feelings; b) the ability to know how others feel and relate to them; c) the ability to manage and control emotions; d) the ability to manage change, adapt and solve problems of personal and interpersonal nature; and e) the ability to generate positive affect and be self-motivated.* [6]

Emotional intelligence was first mentioned prominently in the psychological literature in the early 1980s. Matthews, Zeidner, and Roberts summarize the origins of emotional intelligence in their work [4] "Emotional Intelligence Science or Myth." Here they describe how the widespread interest in emotional intelligence spans business, nursing, medicine, and engineering. This interest then continues as a catalyst for educational reforms. The rest of their work lays a foundation for acceptance or rejection of the current definitions and assessments of emotional intelligence. In their conclusions, two distinct groups emerge: the first group's interpretation of emotional intelligence is strictly parallel to cognitive intelligence and the second group defined EI an all-encompassing value.

These distinctions lead to several different definitions of EI. Roberts, in a summary of emotional intelligence [7], splits EI into two models: Integrative-Model Approaches and Mixed-Model Approaches to emotional intelligence. The Integrative-Model assessment focuses on specific abilities to obtain a measure of EI, an example being the Emotional Knowledge Test [8] and the Mayer-Salovey-Caruso Emotional Intelligence Test (MSCEIT) [9], [10].

The mixed model approach is coined because the assessment includes non-ability measures and intelligent behaviors [6], [11], [12], [13]. These types of mixed approaches work to evaluate concepts such as emotional perception but then add in scales such as happiness and stress tolerance [6].

Pérez [14] defines the difference in emotional intelligence not by the approach of the model but by the distinction of concept. This concept leads to trait EI, also known as emotional self-efficacy and ability EI, also known as cognitive-emotional ability. Pérez argues that the difference between mixed and ability models "pay no heed to the most crucial aspect of construct operationalization (i.e., the method of measure)." He goes on to defend the successful assessment of trait EI through self-reporting but states that self-assessment cannot measure actual cognitive abilities.

Models that measure trait EI consist of the Emotional Quotient Inventory (EQi-2.0) by Multi-Health Systems (MHS), Self-Report Emotional Intelligence Test (SREIT), and the Multidimensional Emotional Intelligence Assessment (MEIA). Each of these assessments are self-reported inventories and includes as many as 133 questions for the EQi-2.0 down to 33 for the SREIT [11], [15], [16].

Specific ability measure tests of emotional intelligence include the Diagnostic Analysis of Nonverbal Accuracy (DANVA), which consists of three versions: Adult Facial Expressions [17], Adult Paralanguage [18] and Posture Test [19]. Ability tests continue with the Emotional Knowledge Test, which uses facial expressions to determine an overall emotion-knowledge score [20]. The Mayer-Salovey-Caruso Emotional Intelligence Scale (MSCEIT) is a famous example of an ability test measuring an overall EI score along with a score for perceiving, facilitating, understanding, and managing emotions [10].

The ability-based measure keeps a strict adherence to the definition of Emotional Intelligence as a term equated to cognitive intelligence (IQ). The description in the most rigid terms is the ability to reason about emotions. Because of this, ability models only report a few variables, and for a model such as the DANVA are only concerned with the accuracy of nonverbal perception of emotions summarized in a single EI score [17]. This single score is also the case for the MSCEIT, although it uses four ability areas to model an overall EI score: accurately perceiving emotions, using emotions to facilitate thought, understanding emotions, and managing emotions [21].

Trait EI uses 10 to 15 scores derived from several different areas. The EQi-2.0 scales consist of 15 scores with five composite scores and a total EI [6]. The scales include factors such as assertiveness, adaptability, and self-regard.

The concept of integrating emotional intelligence into engineering is not new. Riemer [22] argues that emotional intelligence skills are on the decline and, as a result, may lead to higher dropout rates. He is also a strong proponent of using emotional intelligence as a tool to increase the communication skills of engineering students [23], [24]. Brackett makes the case that emotional intelligence is a valuable tool that can be used to facilitate positive growth within the individual, setting them up for success in the workplace [25]. Strobel and Walther [26], [27] reason that empathy, one of the measured values in trait emotional intelligence, is vital and should be cultivated in the engineering field.

Cech [28] shows that as a student progresses through their engineering education, the importance of Ethical and Social issues decreases, as reported by students, thus establishing empathy as a necessary addition to the engineering field.

Empathy is a component of emotional intelligence that is measurable by most assessments. Reimer makes the case that emotional intelligence, as measured by these scales, is reflective of a person's overall communication skills. As such, there may also be a link of these same emotional intelligence scales to the engineering design process. The effective design process starts with empathy for the customer as the priority [29].

The EQi-2.0 reports 21 scores, which include 15 individual metrics. The individual metrics are grouped into five composite scores and a total score. These scores set up the basis for the comparison of the development of the student to their process of solving an open-ended design problem. The variables from the EQi-2.0 include a total score along with the variables in Table 1.

Table 1 EQi-2.0 Scales

Self-Perception	**Decision Making**	**Interpersonal**
Self-Regard	Problem Solving	Interpersonal
Self-Actualization	Reality Testing	Relationships
Emotional Self-Awareness	Impulse Control	Empathy
Self-Expression	**Stress Management**	Social Responsibility
Emotional Expression	Flexibility	
Assertiveness	Stress Tolerance	
Independence	Optimism	

Emotional intelligence defines decision making as "the ability to use your emotions in the best way that helps solve problems and make optimal choices" [30]. A student measuring high in this area should exhibit the ability to grasp problems and determine effective solutions, create solutions that go beyond theory, and manage emotions that may hinder effective decision making. When cast in the context of engineering design, a high score in decision making should be a positive indicator of a sound design engineer.

The other sub-scales of the EQi-2.0 assessment include stress management, self-perception, self-expression, and interpersonal. Stress management is defined as the ability to be flexible, tolerate stress, and control impulses. An engineering designer also needs to possess these skills to complete the design process.

Table 2 Emotional Intelligence Difference Pairings

Additional variables of interest from the EQi-2.0 assessment include balancing scores. Balancing scores are the difference between two of the categories measured. The MHS assessment training defines each of the balancing scores establishing a difference of 10 as significant, thus pointing to an individual who likely exhibits one set of behaviors more often than the other set [31]. Although MHS labels these scores as balances in this paper, we refer to them as difference scores, which is descriptive of what they are. These difference scores are chosen by MHS primarily because of a high correlation with the corresponding scale. What this means is that within the normed group, a positive relationship has been found between the two scales in the difference score. Because of this, individuals who do not follow this trend have a high difference score and are outside the norm group. Table 2 shows the difference relationships for all EI scales. The individual difference pairing can be determined by subtracting the inner circle of Table 2 with one of the three adjacent EI variables on the outside ring. The difference variable is noted in this paper by the two defining EI scales separated by a forward slash; for example, the difference score of self-regard with problem solving is indicated as self-regard/problem solving.

Measuring the design process has become the most challenging question for this research. ABET defines engineering design as [32]:

The process of devising a system, component, or process to meet desired needs. It is a decision-making process (often iterative), in which the basic sciences, mathematics, and engineering sciences are applied to convert resources optimally to meet these stated needs.

Work completed by Atman and Adams [1], [2], [3], [5] established a way for us to assess the cognitive design process of engineering students. Deriving work from Cross [33], Atman and Adams [3] conducted research experiments to determine the differences between how a freshman student completes a design project in comparison to the process a senior engineering student would follow. This work was later expanded to include engineers that had been in the field for an average of 19 years ranging from 7 to 32 years in the engineering field. For their work, these engineers are considered expert designers [2].

The method employed by Atman and Adams was that of a verbal protocol analysis of each student going through a design problem. The initial work used a simple ping pong ball design and a road crossing design problem. However, for their later work, including experts, they developed a playground design problem.

The verbal protocol utilized the think-aloud method, where students verbalized their thoughts as they solve a design problem. This idea of using verbal reports as data in the research community dates back to Simon and Ericsson in 1980 [34], [35], and then refined for the use with engineering students in 1998 by Atman and Bursic in their work [1]. Verbal protocols are useful because a student can verbally express what they are thinking without affecting their cognitive process. Coding categories from Atman are listed in Table 3.

Table 3 Design Protocol Coding

(PD) Problem Definition	Defining what the problem is.
(GATH) Gather Information	Searching for and collecting information needed to solve the problem.
(GEN) Generate Ideas	Thinking up potential solutions to the problem
(MOD) Modeling	Detailing how to build a solution to the problem. Applies to initial solution concepts as well as to the final design.
(FEAS) Feasibility	Assessing and passing judgment on a possible or planned solution to the problem.
(EVAL) Evaluation	Comparing and contrasting two or more solutions to the problem on a particular dimension such as strength or cost.
(DEC) Decision	Selecting one idea or solution to the problem from among those considered.
(COM) Communication	Communicating elements of the design in writing, or with oral reports to parties.
(OTH) Other	None of the above codes

Two other variables included in the work of Atman and Bursic is the number of transitions made between design activities and the rate of the change between design activities per minute. Individual coding segments in Table 3 were used to determine the number of times an individual would transition from one activity to a different activity.

The problem students are asked to solve "the ping pong ball problem" adapted from Atman's work [3]. The only change was to alter the name of the dorm building to represent a location at the South Dakota School of Mines and Technology.

> ***Ping Pong Problem***
> *In an attempt to avoid boredom at Peterson Hall, creative engineering students developed a challenging new game. A ping-pong ball is to be launched at a bull's-eye target, and points are awarded according to the accuracy of the landing. However, the ping-pong ball cannot be thrown at the target. It is up to you to design a device that will lift the ping-pong ball into the air and land it at the target. An accurate landing is desired while also maintaining a long flight time. Given that the center of the landing area is 5 meters away from the launch site and the entire launching assembly must not be greater than 1m X 1m in dimension, design a ping-pong ball launcher for this game.*
> *Your work should contain a detailed description of your design and should include any relevant diagrams and calculations. Please clearly state all assumptions which are needed in your analysis and try to keep your design simple yet effective.*

The design challenge was presented to the participant in a small office after instructions were given about how to complete the "think aloud" verbal protocol. This method, in its purest form, is to speak everything that is being thought without concentrating on what is being said. A practice math problem was administered as a warm-up, and then the design challenge. The session was audio-recorded, and the researcher used the audio recording to gather data.

Transcription, segmentation, and coding was completed on the design problem using the NVIVO11© software, and the variables were aggregated by a single researcher into usable data and compared with the emotional intelligence scores. Using the definitions from Table 3, coding each segment of the transcript into the most appropriate area was completed. For example, a statement of modeling would be: “I would say this design does not need to be any more than about half a foot.” “3 inches will be the diameter of this cup with a depth of about one inch.” A second coder produced inter-rater reliability of 0.88 on a small sample of transcripts to ensure reproducibility in the coding process.

Results of the EQi-2.0 were not presented to the researcher in a way that could identify the student until all transcriptions were coded. This procedure minimizes some possible coding bias.

Of the 37 participants, seven identified as female. The majority engineering major consisted of mechanical engineering, with representation from electrical, chemical, metallurgical, and civil engineering. The average age of the group was 21 years old, and participants had an average of 2.3 years spent at university.

A total of 13 independent design variables were compared to the emotional intelligence variables with a Pearson’s Correlation using IBM SPSS 24©. Due to multiple comparisons, presented here are ten correlations with the lowest statistical p-value. This value corresponds to all design variables having a probability value of less than .007 with a population size of 37. The researcher chose this value to account for type 1 error correction, but most correction factors such as Bonferroni are incredibly conservative. Since this is a small initial study, no matter what multiple comparison correction is used, the ranked p values remain the same.

Half of the correlations discussed here are with the EI difference of stress tolerance/problem solving. This value is defined as a positive difference when stress tolerance is larger than the problem solving score.

A high score in stress tolerance/problem solving may lead to an individual who is calm under pressure, resilient in tough times and manages emotions well during times of stress. However, this person may become overwhelmed with the responsibility of making a decision or may not be able to get past the emotions involved in making a decision. Although this individual is stress tolerant, this factor is opposed by the low problem-solving score. This value is correlated to a high number of activity transitions, total time spent, and percent of time developing alternative solutions shown in Table 4.

Table 4: Stress Tolerance / Problem Solving Correlations

Pearson's Correlation					
Stress Tolerance/ Problem Solving	Total Activity Transitions	Time Spent (Min)	Problem Scoping	Problem Definition	Developing Alternative Solutions
	$.495^{**}$	$.500^{**}$	$-.484^{**}$	$-.470^{**}$	$.461^{**}$
	$p = 0.00184$	$p = 0.00161$	$p = 0.00242$	$p = 0.00330$	$p = 0.00408$
2-tailed significance N=37					

A negative score in stress tolerance/problem solving would indicate a higher score in problem solving than stress tolerance. This individual may maintain focus on the problem and use their emotions to solve problems, but with lower stress tolerance, the emotions used to solve problems may get in the way of coping with the stress of solving the problem. Individuals with a low score in stress tolerance/problem solving could spend a greater percentage of time in the problem scoping stage and completing the problem definition activity. It is worth noting that problem definition activity is a subset of the problem scoping stage, although presented in as two variables, they are not independent of one another.

Table 5: Stress Tolerance / Flexibility Correlations

Pearson's Correlation	
Stress Tolerance/ Flexibility	Total Activity Transitions
	$.436^{**}$
	$p = 0.00695$
2-tailed significance N=37	

A high score in the stress tolerance/flexibility difference is for an individual who has a variety of coping strategies to deal with stress while being rigid in their thinking and behavior. This person may be a resilient individual who can remain composed when times get tough. However, this person likely finds it challenging to deal with the emotions of change. Shown in Table 5 is the single positive correlation with the total number of activity transitions. The individual described above may complete the design problem by transitioning between the coding activities more often than the norm.

Table 6: Interpersonal Relationships / Problem Solving Correlations

Pearson's Correlation	
Interpersonal Relationships/ Problem Solving	Time Spent (Min)
	$.500^{**}$
	$p = 0.00161$
2-tailed significance N=37	

A moderate positive link between time spent and interpersonal relationships/problem solving shown in Table 6. Interpersonal relationship/problem solving may indicate an individual who can build and maintain authentic relationships but struggles to get past their emotions when solving a problem.

This person may be amicable and fun but is easily distracted by emotions, and possibly this emotional distraction could be, in part, a reason for spending an increased amount of time attempting to solve the design problem.

An individual with a high emotional self-awareness/emotional expression difference may be able to label and describe their emotions accurately but may be uncomfortable expressing those emotions. Internally this individual may understand their feelings and be conscious of the impact emotions have on their performance, but they may appear withdrawn or uneasy in emotional situations.

As shown in Table 7, an individual with a high score in this area may spend a significant amount of time generating ideas and a low amount of time modeling the problem or solution concepts.

Generating ideas is defined as time spent determining alternate solution concepts for the design problem. Generating ideas also includes establishing the primary system and brainstorming concepts for sub-components of the system.

The modeling activity is the time spent determining the physical parameters of the device, along with conducting calculations. For this design problem, time spent modeling includes solving the projectile motion problem, potential and kinetic energy, and strength related issues.

Table 7: Emotional Self-Awareness / Emotional Expression Correlations

Pearson's Correlation		
Emotional Self-Awareness/ Emotional Expression	Generate Ideas	Modeling
	.490**	-.561**
	p = 0.00207	p = 0.00031
2-tailed significance N=37		

Contrast the positive difference score with the individual with a negative difference in emotional self-awareness/emotional expression. This individual may spend a significant time modeling the solution concepts but very little time generating those same concepts. An individual with a high emotional expression score may understand the benefits of emotional expression and can express themselves through words. However, with a lower emotional self-awareness score, they may have difficulty recognizing this emotion within themselves or in others. This difference may lead to an individual who appears detached from experiencing emotions. Although appearing detached, this individual is driven to spend time modeling the generated solution concept.

Even though the feasibility activity averaged only 7% of the time spent completing the design challenge, there is one significant link between EI and feasibility. Feasibility is defined as the time spent validating the solution against a set of parameters.

A moderate negative link is shown between the feasibility activity and self-actualization/reality testing shown in Table 8.

Table 8: Self-Actualization / Reality Testing Correlations

Pearson's Correlation	
Self-Actualization/ Reality Testing	Feasibility
	$-.443^{**}$
	p = 0.00605
2-tailed significance N=37	

A high difference of self-actualization and reality testing may act with a higher plan for the moment and be on a continual path of lifelong learning. However, this individual may be looking at the world through rose-colored glasses, only seeing things the way they wish to see it, not actually how it is. This individual will most likely set goals, but with a lower Reality Testing score, these goals probably are unrealistic, or the methods used to determine how to complete a goal may be flawed. This sense of unrealistic or flawed goals may be why this individual may spend little time in the feasibility activity.

Trends in the data reveal that most design time is spent in the problem definition, generating ideas, or modeling activities. Most commonly, participants trade the generating ideas activity with the modeling activity and vice versa. For example, if an individual spends most of their time modeling, they spend little time generating ideas. It is important to note that this type of design activity trade is not seen between any of the other design activities.

Standard correlations between EI and design process are numerous and presented here are the top ten. Although the most substantial relationships are moderate, this is not a surprise given the number of participants in our study.

The biggest take away from this research is not defining how an expert engineer might look within their emotional intelligence profile, but rather how we can use EI to educate the social and emotional aspects of engineering students and demonstrate its connection to the process of design.

This information could be used to compose a design team which contains at least one individual whose strength is in each of the design activities to form a diverse thinking design team. As an engineer, understanding that high scores in problem solving and empathy may mean a preference for spending more time defining the problem may give insight into how this individual can best contribute to a group. Also, if an individual has a high score in problem solving and a lower score in stress tolerance, defining the problem may be where this individual spends a significant amount of time. Individuals who score highest in emotional expression, and lower in emotional self-awareness may find they prefer to spend time in the modeling activity. This difference is then contrasted by the individual who has high emotional self-awareness and lower emotional expression spending a significant percentage of the time generating ideas.

Our research revealed a possible connection between how an individual tackles an open ended design problem and their emotional intelligence scores. Although we cannot imply cause and effect, we should not ignore findings showing a social-emotional connection to the process of design. As educators in design, we must begin to consider the possibility that there is more to the design process than a simple set of steps that need to be followed to formulate a design solution.

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