2023 Annual Conference & Exposition
Baltimore Convention Center, MD | June 25 - 28, 2023
The Harbor of Engineering Education for 130 Years
ASEE
Paper ID #37247

A Multi-Method Analysis of Engineering Student Curiosity

Dr. Meagan Eleanor Ita, Arvinas

Dr. Meagan Ita is a Research Scientist at Arvinas working to develop disease modifying therapies for neurodegenerative diseases. Her career passion is to develop novel biotechnologies and therapeutics to better understand human physiology with the goal of equitably extending healthspan, ideally at the intersection of healthcare and STEM education. Meagan has experience as a Postdoctoral Scholar in Engineering Education from The Ohio State University (OSU), earned a Ph.D. in Bioengineering from the University of Pennsylvania and an M.S. and B.S. in Biomedical Engineering from OSU.

Ms. Amanda Marie Singer, The Ohio State University

Amanda Singer is a second-year PhD student in the Department of Engineering Education at The Ohio State University. She graduated in 2021 from Michigan Tech with a Bachelor's and Master's of Science in Environmental Engineering. Her current research interests include engineering identity formation, community college engineering education, and mixed methods research.

Dr. Rachel Louis Kajfez, The Ohio State University

Dr. Rachel Louis Kajfez is an Associate Professor in the Department of Engineering Education at The Ohio State University. She earned her B.S. and M.S. degrees in Civil Engineering from Ohio State and earned her Ph.D. in Engineering Education from Virginia Tech. Her research interests focus on the intersection between motivation and identity, first-year engineering programs, mixed methods research, and innovative approaches to teaching. She is the principal investigator for the Research on Identity and Motivation in Engineering (RIME) Collaborative.

A Multi-Method Analysis of Engineering Student Curiosity

Abstract

Curiosity, an ability vital to the process of invention and innovation, has also been correlated with a variety of desirable outcomes in education and is recognized as a desirable characteristic in engineering students and practicing engineers. Thus, developing and integrating a curriculum that instills and fosters curiosity in engineering students is essential. To assess student development of curiosity, a direct and an indirect assessment for curiosity were integrated into the curriculum for a first-year engineering honors program at a large midwestern university. The Five-Dimensional Curiosity Scale (5DC), a 25-item instrument developed by Kashdan and colleagues, was implemented as the indirect assessment. The direct assessment for curiosity was developed by the research team and tasks students to brainstorm about a topic and then write 10 distinct questions about that topic. Both assessments were administered at two time points in the academic year. A subset of data of 54 students, randomized across course sections, was selected for analysis.

For the indirect Likert-type survey data, means were computed for each of the five constructs per participant, and pre and post responses were compared using a paired t-test or Wilcoxon signed rank test based on data set normality. To evaluate the direct assessment data, the 10 questions generated by students were analyzed using a deductive coding approach which was guided by a codebook derived from the 5DC. Differences in the frequency of the question codes between pre and post implementations were tested using Pearson correlation tests.

We found a significant increase ($p<0.05$) in student self-reported pre post scores for Social Curiosity and Thrill Seeking constructs over the first year. Despite those constructs increasing, students generated questions pertaining to Information Seeking and Stress Tolerance constructs most frequently in the direct pre and post assessment, with approximately 60% and 25% of questions coded into those categories, respectively. The frequency of codes was not different between the pre and post assessments. These findings suggest that further work is needed to understand discrepancies between how students perceive their curiosity personality and how they exercise that curiosity in an academic context. This paper explores the direct and indirect assessment data sets and discusses implications for our findings on pedagogical approaches to fostering curiosity in first-year engineering.

Introduction

Curiosity, a force that motivates people to seek out new information and discover new things, is vital to the process of invention and innovation and is inextricably linked as a valuable trait for engineers to possess [1]. Beyond its connection to innovation and societal advancement, the ability for one to be curious has also been correlated with a variety of desirable outcomes in education, including increased motivation [2,3], greater ability to retain information and persevere [4], improved learning [2] and increased academic achievement [5]. Additionally, it is strongly associated with a willingness to embrace uncertainty and unpredictability [6,7], traits that are often desirable characteristics for engineering students and practicing engineers. Thus, developing and integrating a curriculum that instills and fosters curiosity in engineering students is essential.

Efforts to integrate a curriculum that fosters curiosity and subsequent calls to provide increased evidence of intervention effectiveness and student learning [8] have resulted in a further need for instruments that assess curiosity. A variety of instruments and mechanisms exist to assess curiosity such as The Perceptual Curiosity Scale [9], The Curiosity and Exploration Inventory [2,10], and The Epistemic Curiosity Scale [11] among others. However, these instruments are diverse in their validity (some are validated while others were created ad hoc) and draw from a variety of theoretical perspectives and fields of study. Although these instruments, such as the Five-Dimensional Curiosity Scale (5DCS) [12], are useful in characterizing curiosity "personalities" using indirect assessment methods, they rely on personal reflection and self-reported abilities that introduce potential inaccuracy and/or misrepresentation of one's true ability to demonstrate curiosity. Instruments to *directly* measure curiosity are needed in parallel with indirect methods to fully capture curiosity through demonstration, yet few such direct assessments exist.

Background

Employers are increasingly expecting new engineers to come to the workplace with an entrepreneurial skillset, which includes curiosity [13]. Engineers with an Entrepreneurial Mindset (EM) have been shown to have skills that are valuable to employers, including analyzing markets, understanding the importance of context, and learning from mistakes [13]. Additionally, in 2015, a survey of American Society for Engineering Education (ASEE) members indicated that both faculty and administrators believe that engineering students should have access to education regarding entrepreneurship and innovation [14]. Therefore, there is an increased effort to fuse EM concepts into engineering coursework.

The Entrepreneurial Mindset at Ohio State

One organization focused on integrating EM concepts into engineering coursework is the Kern Entrepreneurial Engineering Network (KEEN) [13]. KEEN is a network of more than 50 universities across the United States that seek to instill an EM into their students through their curriculum. KEEN operationalizes EM into the "3C's", which represent a set of desired Entrepreneurially Minded Learning (EML) outcomes that include Curiosity, Connections, and Creating Value [13]. The Ohio State University (OSU) began its partnership with KEEN in 2017 and has since integrated the 3C's into many courses across the College of Engineering. These initiatives began with the restructuring of the design-build course in the First-Year Engineering Program (FYEP) standard sequence [15] and have expanded to the FYEP honors sequence, Capstone courses, and intermediate engineering courses. Efforts to assess students' EM have paralleled these integrations, including the development of 14 Entrepreneurial Mindset Learning Objectives (EMLOs) [16] and a "toolkit" of direct and indirect assessments for each of the 3C's [17]. OSU's established EMLOs have since guided EML curricular development throughout the undergraduate engineering program.

Over the last two years, several changes guided by the EMLOs have been made to the FYEP honors sequence. These include the implementation of an "EM workshop" that includes activities on all 3C's as well as chances to provide more emphasis on user needs and problem/ opportunity identification on design projects [18]. Using assessments from our 3C's toolkit, we have also shown that students exhibit growth over the academic year in their self-perceived abilities to make Connections and in their indirectly and directly measured abilities to Create Value [19, 20]. These assessment data provided evidence to support the notion that our curricular changes affected students' EM attributes of Connections and Creating Value over the academic year, yet we have not yet reported assessment data to support students' growth in the Curiosity attribute.

Measurement and Assessment of Curiosity

The 5DCS, developed by Kashdan and colleagues [12], is a product of efforts to consolidate and synthesize decades of research on the theoretical perspectives of curiosity into one comprehensive framework. Data collected from three discrete surveys – a community survey of 508 adults, an Mturk survey of 403 adults, and a nationally represented household survey of 3000 adults, were analyzed using factor analysis. From this analysis, the authors found evidence for five distinct factors, including Joyous Exploration, Deprivation Sensitivity, Stress Tolerance, Social Curiosity, and Thrill Seeking. The authors argue that each factor has relationships with personality, emotional, and well-being measures, and used these results to define 4 distinct types of curious people (i.e., the Fascinated, the Problem-solvers, the Empathizers, and the Avoiders). Although developed within the field of psychology, the 5DCS has been adapted and used across many fields including Behavioral Sciences [21], Social Psychology, Computer Science [22], Mathematics Education [23] and Engineering Education [24]. In fact, researchers at our institution have previously used the 5DCS in the FYEP standard sequence to show that students' Social Curiosity increased significantly following EML infusion into the design-build course [15], demonstrating that the 5DCS can detect measurable changes in OSU's FYEP and provide data to better understand how curricular changes impact students' curiosity. Thus, the 5DCS was implemented as an indirect measure for assessing curiosity in this study due to its comprehensive approach to operationalizing curiosity and its shown ability to detect curiosity changes due to curricular enhancement and change.

The goal of this study was to measure the EM attribute of Curiosity in first-year undergraduate engineers in the FYEP honors sequence in parallel with ongoing EML curricular changes. To accomplish this goal, we aimed to capture both indirect and direct measures of students' curiosities. To do so, we present the development of a *direct* assessment to measure curiosity and implement this in parallel with the 5DCS as an indirect instrument. With this work, we seek to address the following research questions: (1) What curiosity constructs do first-year engineering students demonstrate? (2) Are the perceived constructs and demonstrated constructs the same or different? and (3) How do the curiosity constructs change over time?

Methods

Implementation and Direct Assessment Development

To investigate first-year engineering students' curiosity, the direct and indirect curiosity assessments were implemented into the FYEP honors sequence at OSU following IRB approved procedures. Each assessment was implemented near the beginning and end of the academic year to collect student responses at two points in time. The direct curiosity assessment was given in week 1 of the Autumn 2021 semester (pre) as an out-of-class journal assignment and in week 14 of the Spring 2022 semester (post) as an out-of-class prework assignment, both via surveys designed in Qualtrics. The indirect curiosity assessment was embedded in a larger Qualtrics survey that included indirect assessments for each of the 3C's [13]. The surveys were given in week 1 of the Autumn 2021 semester (pre) as an out-of-class prework assignment and in week 13 of the Spring 2020 semester (post) as an out-of-class journal assignment. A total of 244 participants of the 318 enrolled provided informed consent to the study. The assessments were implemented into the FYEP courses as routine class work and, as such, no individual demographic information was collected. A subset of data from 54 participants was selected for analysis. Participants in this sample came from the population summarized in Table 1. The subset was chosen by first selecting participants who completed each of the four assessments (pre/post for direct and pre/post for indirect) and then selecting 5-7 participant responses at random from each of the 9 sections of the course offering. The results presented in this paper are representative of this sample subset. Furthermore, analysis of the indirect assessment data for the entire sample (n=244) reflects the same statistically significant outcomes as those in the subset we present here.

Table 1. Ethnic, sex, and major demographics of students enrolled in the FYEP honors sequence in Autumn 2021

URM status	**Number**	**Percentage**
Non-URM	305	95.9
URM	13	4.1
Sex	**Number**	**Percentage**
Male	246	77.4
Female	72	22.6
Major	**Number**	**Percentage**
Aerospace Engineering	35	11.0
Aviation	4	1.3
Biomedical Engineering	42	13.2
Chemical Engineering	34	10.7
Civil Engineering	4	1.3
Computer Science and Engineering	105	33.0
Electrical and Computer Engineering	19	6.0
Environmental Engineering	7	2.2
Engineering Physics	4	1.3
Food, Agricultural, and Biological Engineering	1	0.3
Industrial and Systems Engineering	8	2.5
Materials Science and Engineering	4	1.3
Mechanical Engineering	50	15.7
Welding Engineering	1	0.3
Total	**318**	**100.0**

URM: underrepresented minority; URM include African American or Black, Hispanic, American Indian/Alaskan Native, and those who identify as Two or More Races, including at least one of the previous categories. Students are only considered as URM if they are a U.S. citizen or permanent resident.

The direct assessment for curiosity, which was developed in-house by researchers at OSU and informed by the dimensions of the 5DCS [12], tasks students with generating a list of questions pertaining to their curiosities surrounding a specified topic. The assessment was designed to be administered in a pre-post fashion to capture changes in student curiosities across two time points. The assessment prompt first asks students to "brainstorm things they are curious about" regarding a specified topic. Then, using the ideas generated during the brainstorming, the students are asked to generate 10 questions they have about the topic. The pre and post assessments administered during the 2021-2022 school year asked students to generate any questions they have "related to engineering," with the pre and post assessment prompts being identical.

Direct Assessment Deductive Coding

We developed an initial codebook that was based on the five curiosity constructs defined in the 5DC [12] to analyze the direct assessment data, with definitions for Joyous Exploration, Deprivation Sensitivity, Stress Tolerance, Social Curiosity, and Thrill Seeking. The 5DC definitions provided an initial basis for a deductive coding process whereby three researchers independently coded questions from the direct assessment curiosity responses into one of the five curiosity constructs. The deductive coding process began with each of the three researchers coding the same set of five participants questions (10 questions/participant), discussing discrepancies, and revising the definitions in the codebook. Through several rounds of coding and refinement, it became clear that the brainstorming section of the direct assessment (submitted along with the 10 questions) was not specific enough to consistently provide insight into the motivation behind the questions. This lack of clarity made it difficult to differentiate between Joyous Exploration and Deprivation Sensitivity questions. Therefore, we combined those two constructs into a singular code named "Information Seeking" (Table 2). Following this adjustment, we coded another set of participant questions and achieved an agreement of approximately 85%. Accordingly, we coded the dataset of 54 responses using the revised codebook (Table 2). During the final coding phase, two researchers coded each question, with a third researcher acting as an arbiter of the final code decision in the event of a disagreement. Of note, questions were not coded if they did not relate to the prompt, were poorly worded, or could not be understood (Table 2). Examples of student-generated questions that were coded across each of these categories are presented in the results in Table 4.

Table 2: Codebook for the direct curiosity assessment based on the 5DC.

Curiosity Construct	Definition	Notes
Information Seeking	Gathering information regarding engineering, but the motivation (e.g., content needed to distinguish between Joyous Exploration and Deprivation Sensitivity) behind the question is not supported by evidence from the student response.	--
Information Seeking-Joyous Exploration	Gathering information regarding engineering, with the motivation of the dictionary definition of curiosity, capturing a preference for new information and experiences, and the valuing of self-expansion over security, strong personal growth initiative, derive positive emotions and meaning from learning new information and experiences.	Motivation can be extracted from the brainstorming section to distinguish from Deprivation Sensitivity.
Information Seeking-	Gathering information regarding engineering with the motivation of seeking information to escape the tension of not knowing something, holding a high	Motivation can be extracted from the brainstorming

Deprivation Sensitivity	epistemic curiosity or a drive to know, intellectually engaged to think about abstract or complex ideas, solve problems, and seek necessary information to eliminate knowledge gaps.	section to distinguish from Joyous Exploration.
Stress Tolerance	Reflects the perceived ability to cope with the anxiety inherent in confronting the new, less deterred by doubt, confusion, and other forms of distress when exploring new places. For the context for undergraduate engineers, this includes questions about future schooling, obtaining a job/being employed/internships and co-ops, and salary and money concerns.	Element of unknown in the future, particularly for the assessment taker. These questions will often include an "I/my" statement, rather than questions regarding the entire engineering field (however, an I/my statement is not required).
Social Curiosity	An interest and even fixation on how other people think and behave using either overt means such as observing and probing questions or covert means such as listening into conversations or gathering second-hand information.	Anytime a question is about another person's behavior, thoughts, or social dynamics between groups. It is NOT about technical aspects of the field, or the technical tasks engineers do.
Thrill Seeking	The belief that a good life is about seeking out pleasure and adventure, especially when significant physical, social, legal, and/or financial risks are required, on the hunt for varied, novel, complex, and intense experience and to have them at the risk of physical, social, and financial safety.	--
Not coded	Questions that do not link explicitly to engineering, engineers, or an engineered product, may also include questions that are poorly words and cannot be understood.	If questions include context words such as "classes" or "projects" those may be coded as if they are related to engineering.

Direct and Indirect Assessment Analysis

To assess whether the types of questions in the direct assessment differed between pre and post implementations, contingency tables were generated with the frequency of code response by time point with the four codes of Information Seeking, Stress Tolerance, Social Curiosity, and Thrill Seeking. With the code as the response (dependent) variable, the time point as the factor (independent) variable, the null hypothesis that the code frequency and time point are independent was tested with a Pearson correlation test. Responses that were not coded were omitted from this analysis. Tests were conducted in JMP Pro 15.2.0 (SAS Institute Inc.) with $\alpha=0.05$.

The 7-point Likert-type scale data from the 5DC survey items were extracted from Qualtrics and the mean was computed for each of the five constructs per participant according to the scoring instructions defined by Kashdan et al [12]. The Likert-type scale uses 7-points which include: (1) Does not describe me at all, (2) Barely describes me, (3) Somewhat describes me, (4) Neutral, (5) Generally describes me, (6) Mostly describes me, and (7) Completely describes me. The means for Joyous Exploration and Deprivation Sensitivity were computed individually as well as pooled to combine them as one construct to align with the Information Seeking construct used in the direct assessment deductive coding (Table 2). A custom MATLAB script was used to test the normality of the pre and post construct means using a goodness-of-fit test for a normal distribution. Pre and post assessment responses were compared using a paired t-test or Wilcoxon signed rank test based on whether the assessment data were determined to be normally or non-normally distributed, respectively.

The change in score over the course of the year was also calculated for each student for each of their direct and indirect scores, separately, by subtracting the student's pre score from their post score for each curiosity construct. For this computation, the pooled Information Seeking construct was calculated; the sub-constructs of Joyous Exploration and Deprivation Sensitivity were not computed since these two constructs were not separately calculated in the direct analyses. Accordingly, a negative change in score indicates that a student scored lower at the end of the academic year than at the beginning and a positive score indicates that a student scored higher at the end of the academic year than at the beginning.

Results

The average student response across the pre and post indirect assessment was near or above a 5.0 on a 7-point Likert-type scale for the Information Seeking construct and its sub-constructs, Joyous Exploration and Deprivation Sensitivity, and for Social Curiosity (Table 3). Students reported that Stress Tolerance describes them the least (Table 3) which was scored in reverse order. There was a statistically significant increase in student self-reported pre to post scores for Social Curiosity ($p=0.002$) and Thrill Seeking ($p<0.001$) constructs (Figure 1), with the average for each construct increasing by over .5 of a Likert-type scale point (Table 3). In Figure 1, Information Seeking represents the pooled data from Joyous Exploration and Deprivation Sensitivity.

Table 3: Descriptive statistics for indirect curiosity assessment.

Curiosity Construct	Pre (AU21) (mean ± SD)	Post (SP22) (mean ± SD)	Change (Post-Pre) (mean ± SD)
Information Seeking (IS)	5.29±0.61	5.26±0.88	-0.01±0.84
Joyous Exploration (JE)	5.34±0.80	5.35±1.00	--
Deprivation Sensitivity (DS)	5.23±0.70	5.13±1.15	--
Stress Tolerance (ST)	1.33±0.55	1.28±0.62	-0.05±0.71
Social Curiosity (SC)	4.83±0.95	5.30±1.11	0.47±1.06
Thrill Seeking (TS)	3.75±1.21	4.31±1.24	0.56±0.93

SD: standard deviation. A total of 54 student responses are included; the same students were included in pre and post to compare paired responses.

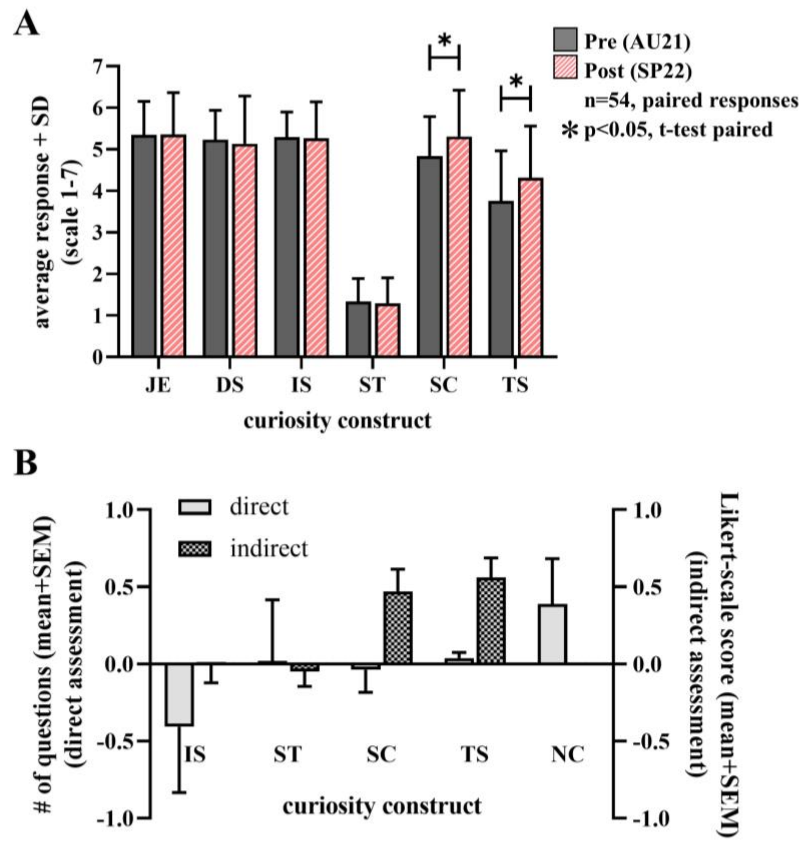

Figure 1: Aggregate data average and standard deviation (SD) from the Five-Dimensional Curiosity Scale adopted as an indirect assessment for Curiosity (**A**). Average change in score and standard error of mean (SEM) over the academic year for both direct and indirect assessments by construct (**B**). Direct-coded questions are shown on the left y-axis, gray boxes; indirect data are shown on the right y-axis, checkered boxes.

In the direct curiosity assessment, students generated questions pertaining to Information Seeking and Stress Tolerance constructs most frequently across both the pre and post assessments, with approximately 60% and 25% of questions coded into the Information Seeking and Stress Tolerance categories, respectively (Table 4). Table 4 displays the frequency of questions per curiosity construct for the Autumn 2021 and Spring 2022 semesters, respectively; column 4 shows the average change in number of questions over the academic year. Pearson correlation tests indicate no significant difference in frequency of codes between the pre and post assessments. On average, there was a decrease in questions coded as Information Seeking, yet this may be explained by an increase in questions that were not coded (Figure 1B). Common themes among student questions included: differences/ similarities between engineering majors, design strategies, technical responsibilities, and social dynamics of professional engineers, how to find a job, co-op, or internship, and how engineered products work (Table 5).

Table 4: Deductive coding results for direct curiosity assessment.

Curiosity Construct	Pre (AU21) (#; % of total)	Post (SP22) (#; % of total)	Change (mean ± SD)
Information Seeking (JE+DS)	340 (63.0%)	318 (58.9%)	-0.41±3.14
Stress Tolerance	133 (24.6%)	134 (24.8%)	0.02±2.91
Social Curiosity	29 (5.4%)	27 (5.0%)	-0.04±1.08
Thrill Seeking	0 (0%)	2 (0.4%)	0.04±0.27

JE: Joyous Exploration; DS: Deprivation Sensitivity. A total of 540 questions were categorically coded, those not included in the table were coded as "no code" and include n=38 pre and n=59 post. The frequency of codes is not different between pre and post for any construct (p>0.05, Chi^2 test). SD: standard deviation.

Table 5: Examples from student responses on the direct curiosity assessment.

Curiosity Construct	Examples
Information Seeking	*Is programming a big part of engineering?* *Do all engineers use some form of the design process?*
Information Seeking-Joyous Exploration	*What will the field of engineering look like 50, 100, 1000 years from now?* *Why don't we have flying cars yet?*
Information Seeking-Deprivation Sensitivity	*Do engineers actually use calculus?* *What is the best way to learn CSE related skills outside of class?*
Stress Tolerance	*How do I know I'll be good at engineering?* *Should I continue my schooling after undergraduate?* *When is the best time to intern/coop?*
Social Curiosity	*How does an engineer visualize large concepts?* *How can two engineers of different fields communicate to create a sufficient project?*
Thrill Seeking	*Will we be able to teleport one day?*
Not coded	*How are humans dealing with overpopulation?* *The mindset of an engineer* *Can anything not be created?*

Discussion

This study presents an integration of an indirect and a direct instrument of a FYEP and a dataset resulting from both instruments acquired at the beginning and end of students' first year as undergraduate engineers. The 5DCS provided an indirect and validated instrument that also served as the foundation for our analysis of student responses to the direct instrument that we developed in-house. Using the 5DCS as a basis for our deductive coding (Table 2) enabled an interpretation of results from both assessments that reveal where students' perceived curiosity constructs and the constructs they demonstrate differ.

Students' perceived curiosity constructs are greatest in Information Seeking, followed by Social Curiosity, Thrill Seeking, and finally Stress Tolerance as the lowest self-perceived construct (Table 3). A low average score on Stress Tolerance indicates that this student population is *more* deterred (relative to a higher score) by doubt, confusion, and other forms of distress when confronting the new and unexpected [12]. This assertion is supported by nearly one-quarter of questions falling in the Stress Tolerance construct on the direct assessment (Table 3). The ordering of constructs on both assessments is independent of the time point in the academic year (Table 3) yet the significant increase in 5DCS-measured Social Curiosity and Thrill Seeking (Figure 1) suggests that students experience more alignment with these constructs at the end of the academic year. An increase in Social Curiosity suggests that students' empathy and interest in what others think and do also rises [12]. Thrill Seekers are individuals with higher risk tolerance and a desire for intense experiences [12], so an increase in this construct may indicate that students perceive a greater comfort with taking risks and/or an increased desire for "out-of-the-box" experiences.

Unlike the indirect measures, the direct measures of the curiosity constructs did not change over time (Table 4) suggesting that students ask questions of similar curiosity "type" at the beginning and end of the academic year. Information Seeking made up most questions asked (Table 4), aligning with scores over 5.0 on the 5DCS (Figure 1). However, the magnitude of occurrence for questions in the other constructs did not align as closely with the results of the 5DCS. For example, despite students' perception of their Social Curiosity and Thrill Seeking curiosities significantly increasing (Figure 1), questions were coded as these constructs the least frequently on the direct assessment, with Thrill Seeking questions being negligible (Table 4). A significant increase in Social Curiosity on the 5DCS (Figure 1) taken together with only ~5% of questions in this category (Table 4) may suggest that students perceive themselves as much more interested in others' thoughts and actions then they act out in daily behavior. Alternatively, the inverse relationship between the direct and indirect results may be explained by students asking the least number of questions about constructs with which they are the most comfortable.

We posit that taken together, our results from the two curiosity instruments suggest our student population most strongly fits into the Problem-solver personality type due to high Joyous Exploration and Deprivation Sensitivity (i.e., Information Seeking in the present study) and low Social Curiosity, according to Kashdan et al. [12]. The Problem-solver personality type endorses independence and desires the resolution of perceived gaps in knowledge [12]. These individuals also report the lowest level of apathy in broader populations and tend to be less interested in understanding others [12], which may have implications for educators as they consider the incorporation of EML components such as value creation and user needs. Of course, we do not conclude that all students follow the average results (Figure 1 and Table 4) nor do our results perfectly track with the Problem-solver 5DCS profile. For example, Problem-solvers have a high Stress Tolerance and our results indicate that our population ranks lowest in this dimension (Table 3 and Figure 1). Nonetheless, an understanding of how a student's 5DCS maps to personality type may be helpful from an educational standpoint. For example, a student ranking high in all dimensions is most closely aligned with the Fascinated personality type and may naturally act as a leader in a group dynamic, whereas a student aligned with the Empathizer type may naturally be drawn to managing conflict and communication in a group [12].

In addition to providing assessment data about the students' curiosity, the 5DCS (indirect) and question generation (direct) results can be leveraged as a learning activity. For example, faculty instructors of Capstone courses at OSU have used the results of the 5DCS as an introductory activity for design project student teams to understand working team roles, much like other personality tests. Furthermore, the post implementation of the direct curiosity assessment presented here was integrated into an individual activity but then used during an in-person reflection discussion amongst students. Students were asked to reflect on the questions they personally wrote at the beginning and end of the year and to discuss similarities and differences, effectively serving as a powerful meta-cognitive exercise.

Studies in the broader literature on the 5DCS and the Revised 5-Dimensional Curiosity Scale (5DCR) suggest connections between the curiosity dimensions and individual attributes that can inform our understanding of student development and approaches to teaching and learning. For example, in Kashdan and colleagues' [25] work introducing the Revised 5DCS, they correlate high scores on measures of Joyous Exploration, Stress Tolerance, and Overt Curiosity (a sub-construct of Social Curiosity pertaining to the interest in other people's behaviors, thoughts, and feelings captured through direct interaction), with feelings of increased autonomy, competence, and belonging. Furthermore, they connect high levels of Deprivation Sensitivity with the need for competence. When applied to our students, the findings of Kashdan and colleagues [25] may suggest that our students seek competence and belonging over the course of the assessment period as their Deprivation Sensitivity scores, although unchanged, remained high between pre and post assessments.

Vernon and Huang [24] have also used the 5DCS in an introductory engineering course to investigate the effects of EML and found results that partially align with the results we present here. Within their implementation of the 5DCS, Vernon and Huang [24] measure outcomes related to the integration of a new module into a First-Year Engineering course. This module, which sought to foster student curiosity about chemical engineering, included a variety of hands-on activities designed to connect chemical engineering concepts and careers. Measures of Social Curiosity significantly increased, and measures of Stress Tolerance significantly decreased, in the group of students who completely the modules relative to the group who did not. Additionally, students who completed the module activities demonstrated an increase in Deprivation Sensitivity scores as compared to their counterparts in the control group who demonstrated a decrease in this construct. The increase in Social Curiosity demonstrated in this work [24] aligns with the findings of our implementation of the 5DCS which also showed an increase between the beginning and endpoints of the FYEP course.

Limitations

The results presented within this paper are a product of the initial implementation of parallel direct and indirect assessments for curiosity in an OSU FYEP honors classroom. To analyze the direct assessments, we used the constructs described in Kashdan and colleagues [12] 5DCS to inform deductive coding of each response into one of the five categories (i.e., Joyous Exploration, Deprivation Sensitivity, Stress Tolerance, Social Curiosity, and Thrill Seeking). The process of coding the responses required many iterations and discussions among the research team. Several rounds of coding and refinement revealed that the brainstorming section of the direct assessment, which was submitted as a part of student responses, did not provide consistent insight into the student's motivation for asking each question. This ambiguity made it difficult to differentiate between Joyous Exploration and Deprivation Sensitivity questions when coding the data, motivating the combination of the two constructs into a singular "Information Seeking" code. Although the utilization of the Information Seeking code within the data analysis allows for the retention of the descriptor "desire to obtain new information" that is common between the two constructs, the combination of the constructs into one code reduces the granularity of the results and the motivation behind seeking new information. Joyous Exploration is recognized as an approach motivation or one that is instigated by a desirable event or possibility whereas Deprivation Sensitivity is an avoidance motivation that is directed by undesirable events [12]. The lack of distinction between these two fundamentally different types of motivation limits the overall utility of this measure.

In addition to the coding procedures, the verbiage of the constructs identified within the 5DCS and the use of these as the basis for our coding procedure may not align well within the context of the first-year students completing the direct assignment. For example, a Thrill Seeking question according to the 5DCS (i.e., a question about skydiving) is out of scope with the questions submitted for the topics utilized in the direct assessment (i.e., questions related to engineering). This disconnect may explain the large amounts of Information Seeking and Stress Tolerance questions generated by students and few Thrill Seeking questions present within student assessments. The subjective nature of the coding process and the potential misalignment between the verbiage of the 5DCS and the FYEP context, collectively, reflect a need to revisit the coding process and codebook.

Conclusions and Future Work

As the number of engineering programs integrating EM into their curricula increases, so too does the need for assessments that measure the effectiveness of curriculum interventions and student development of an EM. While a variety of such assessments exist, most assess EM holistically and lack the capability of individually assessing the attributes (i.e., the 3C's: Curiosity, Connections, and Creating Value) recognized as defining an EM. This paper presented the development of a direct assessment for measuring curiosity and its subsequent implementation in an FYEP classroom. The direct assessment was administered in parallel with an indirect assessment of curiosity (i.e., the Five-Dimensional Curiosity Scale [12]) to capture the self-reported curiosities of students and those they directly demonstrate. Through this implementation, we found that students perceived curiosity constructs are greatest in Information Seeking, Social Curiosity, and Thrill Seeking, and lowest in Stress Tolerance. Significant increases in the student self-reported pre to post scores for Social Curiosity and Thrill Seeking constructs emerged within the data, with the average for each construct increasing by over .5 of a Likert-type scale point. However, differences arose between student indirect and direct assessment pre-post scores, highlighting the utility of a curiosity assessment that directly measures student curiosity and the use of the direct and indirect assessments in parallel to fully characterize student curiosity as it relates to an EM. Future work will focus on adapting the existing codebook to better align with the 5DCS constructs in the context of a first-year engineering classroom and to differentiate between overt covert social curiosity, sub-constructs distinguished by Kashdan et al., [25] in the Revised Five-Dimensional Curiosity Scale (5DCR).

References

[1] D. Pusca and D. Northwood, "Curiosity, creativity and engineering education," *Global Journal of Engineering Education*, vol. 20, no. 3, pp. 152–158, 2018.

[2] T. B. Kashdan, P. Rose, and F. D. Fincham, "Curiosity and exploration: facilitating positive subjective experiences and personal growth opportunities," *J Pers Assess*, vol. 82, no. 3, pp. 291–305, Jun. 2004, doi: 10.1207/s15327752jpa8203_05.

[3] Y.M. Tsai, M. Kunter, O. Lüdtke, U. Trautwein, and R. M. Ryan, "What makes lessons interesting? The role of situational and individual factors in three school subjects.," *Journal of Educational Psychology*, vol. 100, no. 2, pp. 460–472, May 2008, doi: 10.1037/0022-0663.100.2.460.

[4] J. M. Harackiewicz, K. E. Barron, J. M. Tauer, and A. J. Elliot, "Predicting success in college: A longitudinal study of achievement goals and ability measures as predictors of interest and performance from freshman year through graduation," *Journal of Educational Psychology*, vol. 94, pp. 562–575, 2002, doi: 10.1037/0022-0663.94.3.562.

[5] S. von Stumm, B. Hell, and T. Chamorro-Premuzic, "The hungry mind: Intellectual curiosity is the third pillar of academic performance," *Perspectives on Psychological Science*, vol. 6, pp. 574–588, 2011, doi: 10.1177/1745691611421204.

[6] C. A. Berg and R. J. Sternberg, "Response to novelty: continuity versus discontinuity in the developmental course of intelligence," *Adv Child Dev Behav*, vol. 19, pp. 1–47, 1985, doi: 10.1016/s0065-2407(08)60387-0.

[7] P. J. Silvia, "Appraisal components and emotion traits: Examining the appraisal basis of trait curiosity," *Cognition and Emotion*, vol. 22, no. 1, pp. 94–113, Jan. 2008, doi: 10.1080/02699930701298481.

[8] W. F. Massy, T.A. Sullivan, and C. Mackie, "Improving measurement of productivity in higher education," *Change: The Magazine of Higher Learning*, vol. 45, no. 1, 15–23, 2013.

[9] R. P. Collins, J. A. Litman, and C. D. Spielberger, "The measurement of perceptual curiosity," *Personality and Individual Differences*, vol. 36, no. 5, pp. 1127–1141, Apr. 2004, doi: 10.1016/S0191-8869(03)00205-8.

[10] T. B. Kashdan, P. J. Silvia, T. B. Kashdan, and P. J. Silvia, "Curiosity and Interest: The Benefits of Thriving on Novelty and Challenge," Jul. 2009, pp. 366–374. doi: 10.1093/oxfordhb/9780195187243.013.0034.

[11] J. A. Litman, H. M. Crowson, and K. Kolinski, "Validity of the Interest- and Deprivation-type epistemic curiosity distinction in non-students," *Personality and Individual Differences*, vol. 49, no. 5, pp. 531–536, Oct. 2010, doi: 10.1016/j.paid.2010.05.021.

[12] T. B. Kashdan *et al.*, "The five-dimensional curiosity scale: Capturing the bandwidth of curiosity and identifying four unique subgroups of curious people," *Journal of Research in Personality*, vol. 73, pp. 130–149, Apr. 2018, doi: 10.1016/j.jrp.2017.11.011.

[13] The Kern Family Foundation, "Engineering Unleashed," https://engineeringunleashed.com/, 2022, (accessed October 2022).

[14] A. R. Peterfreund, E. Costache, H. L. Chen, S. K. Gilmartin, and S. Sheppard, "Infusing Innovation and Entrepreneurship into Engineering Education: Looking for Change as Seen by ASEE Members, 2012 to 2015," presented at the 2016 ASEE Annual Conference & Exposition, Jun. 2016. Accessed: Jan. 16, 2023. [Online]. Available: https://strategy.asee.org/infusing-innovation-and-entrepreneurship-into-engineering-education-looking-for-change-as-seen-by-asee-members-2012-to-2015

[15] D. M. Grzybowski, X. Tang, E. Park, A. Leonard, J. DeLano, and K. Zhao, "Integration of Entrepreneurial-minded Learning," presented at the 2020 ASEE Virtual Annual Conference Content Access, Jun. 2020. Accessed: Jan. 16, 2023. [Online]. Available: https://strategy.asee.org/integration-of-entrepreneurial-minded-learning

[16] L. E. Rumreich, F. Logan, Z. Dix, N. R. Sattele, K. M. Kecskemety, and A. D. Christy, "Comparison of Entrepreneurial Mindset Course Learning Objectives: Evaluating Consistency and Clarity," presented at the 2020 ASEE Virtual Annual Conference Content Access, Jun. 2020. Accessed: Jan. 16, 2023. [Online]. Available: https://strategy.asee.org/comparison-of-entrepreneurial-mindset-course-learning-objectives-evaluating-consistency-and-clarity

[17] M. West, M. E. Ita, L. Rumreich, R. L. Kajfez, and K. M. Kecskemety, "Development of a Direct Assessment for Measuring Students' Ability to Make Connections," presented at the 2021 ASEE Virtual Annual Conference Content Access, Jul. 2021. Accessed: Jan. 16, 2023. [Online]. Available: https://peer.asee.org/development-of-a-direct-assessment-for-measuring-students-ability-to-make-connections

[18] P. Herak, B. Cohen, and M. E. Ita, "Using Themes to Emphasize User-Centered Design in First-Year Engineering," presented at the KEEN National Conference, Atlanta, Georgia, Jan. 27, 2023.

[19] Ita, M., West, M., & Kajfez, R., "Development of Two Instruments to Measure Ability to Make Connections and Create Value in Engineering," *International Journal of Engineering Education*, under review 2023.

[20] S. Youssef, M. E. Ita, Rachel L. Kajfez. "Student Comprehension of and Growth in Creating Value with an Entrepreneurial Mindset," accepted to the 2023 ASEE Annual Conference, Baltimore, Maryland, June 2023.

[21] M. Birenbaum, F. N.-A. Alhija, H. Shilton, H. Kimron, R. Rosanski, and N. Shahor, "A further look at the five-dimensional curiosity construct," *Personality and Individual Differences*, vol. 149, pp. 57–65, Oct. 2019, doi: 10.1016/j.paid.2019.05.038.

[22] M. A. G. Maureira and I. Kniestedt, "Games that Make Curious: An Exploratory Survey into Digital Games that Invoke Curiosity," presented at the 17th International Conference on Entertainment Computing (ICEC), Sep. 2018, vol. LNCS-11112, p. 76. doi: 10.1007/978-3-319-99426-0_7.

[23] A. Taram and F. Setyawan, "Stress Tolerance in Probabilistic Thinking: A Case Study," *Mathematics Teaching Research Journal*, vol. 14, no. 4, 2022.

[24] J. Vernon and Y. Huang, "Work in Progress: An Evaluation of a First-year Chemical Engineering Module on Students' Curiosity and Connectivity," presented at the 2020 ASEE Virtual Annual Conference Content Access, Jun. 2020. Accessed: Jan. 16, 2023. [Online]. Available: https://strategy.asee.org/work-in-progress-an-evaluation-of-a-first-year-chemical-engineering-module-on-students-curiosity-and-connectivity

[25] T. B. Kashdan, D. J. Disabato, F. R. Goodman, and P. E. McKnight, "The Five-Dimensional Curiosity Scale Revised (5DCR): Briefer subscales while separating overt and covert social curiosity," *Personality and Individual Differences*, vol. 157, p. 109836, Apr. 2020, doi: 10.1016/j.paid.2020.109836.