Engineering Educators Bringing the World Together
2025 ASEE Annual Conference & Exposition
Palais des congrès de Montréal, Montréal, QC • June 22–25, 2025
Paper ID #47177

WIP: Confirmatory Factor Analysis of Instruments to Measure Connections and Creating Value in First-Year Engineering Students

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Introduction

To effectively tackle global challenges and meet industry demands, it is crucial for today's engineering graduates to possess both technical expertise and professional skill competencies [1] - [5]. In response to this need, the Kern Entrepreneurial Engineering Network (KEEN) has identified the 3Cs (Curiosity, Connections and Creating Value) for supporting the development of an Entrepreneurial Mindset (EM) in engineering [6] - [8]. Cultivating an EM, and associated behaviors, with first-year engineering students is one positive step towards fostering students' professional skill development and preparing them for their future undergraduate courses and career roles.

To achieve this goal, Entrepreneurial Minded Learning (EML) was incorporated into the engineering undergraduate programs at a large Midwestern University. These initial efforts in the implementation of EML included curricular changes in the first-year engineering courses and the development of several assessment tools to ensure that both faculty and students were exposed to the constructs. For continuous improvement of EML infused curricula, the university developed and implemented such tools centralized in KEEN’s 3Cs.

The preliminary construct validation of the indirect assessment instruments included using KEEN’s definitions and the university’s established 14 Entrepreneurial Mindset Learning Objectives (EMLOs) to develop two indirect survey instruments that measure Connections and Creating Value [9]. The initial investigation into the construct validity of the indirect assessment instruments used an Exploratory Factor Analysis (EFA) to identify theoretical factors present within the constructs of Connections and Creating Values [9]. Building on this prior work, this work-in-progress (WIP) paper describes the continuation of examining the construct validity for indirect assessment instruments (surveys) measuring Connections and Creating Value using Confirmatory Factor Analysis (CFA).

Background

Since 2017, the Ohio State University (OSU) has been an active member and partner with KEEN to incorporate EML into undergraduate engineering education programs. The engineering education department at the university led this partnership and initiative beginning with the implementation of EML into the design-build courses within the First-Year Engineering Program (FYEP) [10]. This adoption of EML was informed by best practices derived from participating in a multi-institutional investigation into formal EM learning approaches in first-year engineering courses [11] - [12]. To ensure that students become familiar with the 3Cs, these constructs were explicitly added to the first-year courses. Cultivating EM in engineering students has been associated with developing a skillset that is valuable to employers such as market analysis, critical thinking, problem-solving, creativity, persistence through mistakes, and many more [12] - [15].

Since the establishment of the KEEN – OSU partnership, there have been many additional initiatives to integrate EM into the engineering curriculum such as the integration of 14 EMLOs for curriculum development [16], creation of rubrics associated with each EMLO, and the development of a toolkit of evaluations for each of the 3Cs including both direct and indirect assessments [17]. For continuous improvement of the first-year engineering curriculum, the EMLOs were regularly evaluated using assessments from the 3Cs toolkit. The data collected through assessments showed evidence of students exhibiting growth in the three constructs [9], [13], [14]. This further bolstered the efforts to establish validation evidence for the indirect assessment instruments for the 3Cs.

While the concepts of Curiosity, Connections, and Creating Value are common phrases and desired traits in engineering specifically, only Curiosity had an existing validated tool that could be used for this work. For assessing the curiosity construct, a validated and widely used tool in engineering education, Five-Dimensional Curiosity Scale (5DC), was adopted [18]. For assessing the other 2Cs – Connections and Creating Value, the researchers developed two indirect surveys. These two surveys were administered in FYEP honors courses in the beginning of Autumn 2021 and the end of Spring 2022.

An EFA was conducted on the data from the Autumn 2021 pre-test, which resulted in the identification of four factors, or subconstructs, for Connections and three factors for Creating Value [9]. These surveys were intended to help inform curricular changes and instructional practices in first-year engineering and thus they were administered to the students at the beginning of the first semester and the end of the second semester of each academic year in a pre/post-test format after that initial pilot. To further extend this validation effort [9], this paper presents a CFA using student assessment data collected in Autumn 2022, 2023, and 2024 to establish more rigorous construct validity evidence for the indirect assessment instruments for Connections and Creating Value.

3. Methods

3.1 Indirect Assessment Instrument (Survey) Description and EFA Subfactors

Two indirect assessment instruments (surveys) were examined in this study. The Connections survey has 18 items, and the Creating Value survey has 21 items [9]. The previous EFA identified four factors for Connections including (1) Integrate Outside Information, (2) Consider Social, Economic, and Environmental Factors, (3) Define Connections, and (4) Make Connections within Engineering Design. An EFA on Creating Value indirect assessment instrument data was also conducted, resulting in three underlying factors: (1) Create Value within Engineering Design, (2) Attitude and Approach Toward Value Creation, and (3) Create Value for Others. Since Autumn 2021 when the original investigation was completed, data collection has been repeated for Autumn 2022, 2023, and 2024, resulting in an additional 700+ student responses to aid in analysis. These cohorts were used for the CFA in this WIP to further refine and validate the assessment instruments for expanded use.

3.2 Data Collection

The data was collected from FYEP students across each Autumn semester from 2022 to 2024. Participant responses were collected using Qualtrics. The data was downloaded and cleaned to exclude any identifying information. In total, 1155 participant responses were collected across all three semesters. The Autumn semester and the first-year cohorts were chosen to ensure consistency with the participant population type used in the previous EFA study and to check if the results held across multiple cohort years.

3.3 Data Analysis

Construct validity is the degree to which an instrument claims to measure a theoretical construct [22] - [25]. To examine the construct validity of an instrument, researchers work to understand the correlation of observed variables and a latent factor through factor analysis. There are two common factor analysis techniques: EFA and CFA. Both measure the extent to which observed variables measure factors of a latent construct are "related" through considering variance and covariance. Where EFA and CFA differ is in the intent of the analysis. EFA is used to explore data in an unrestrictive manner to reveal underlying factors or bundles of observed variables to create hypothesis from data. CFA utilizes factor analysis in a restrictive manner to test a hypothesis. Typically, this involves the confirmation of factors uncovered from an EFA analysis. Thus, a CFA looks at how well a model fits by observed data, testing the hypothesis through pilot study data [23].

The extent of pilot data needed to conduct CFA is ill-defined in literature. The issue of sample size within CFA lies in the variability of recommendations and the lack of authors expressing concerns with sample size within factor analysis [27] - [30]. Recommendations in the literature for sample size in conducting CFA range from 150 to 1000 subjects, with researchers commonly citing data features as decision influences, such as the normality of data and the methods utilized when estimating parameters [31] - [34]. [32] describes a commonly used practice of using the ***N:q rule***. It is suggested that when establishing a minimum sample size, they should consider the ratio of the number of cases (N) to the number of parameters estimated (q), with the recommendation being 20:1. Each indirect assessment instrument has two estimated parameters: (1) the factor loading between the observed variable and factor and (2) the residual variance of each observed variable. Because the Connections assessment instrument has 18 observed variables (items) and the Creating Value assessment instrument has 21 observed variables, the *q* for Connections and Creating Value are 36 and 42 respectively. Thus, a sample size of 720 and 840 are identified as the minimum sample size needed to conduct CFA on the indirect assessment instruments. Given the sample size acquired for this study is an *n* of 1155 students, we find the sample size adequate to construct meaningful claims about factor loadings and model fit metrics for both indirect instruments.

CFAs are evaluated in two ways: (1) the global, or overall, fit of the theoretical model to the observed data and (2) the item-level factor loadings which are individual correlations between items and their corresponding factors from the theoretical model. To evaluate the global fit of the model, multiple indices were considered: Comparative Fit Index (CFI), Tucker Lewis Index (TLI), Root-Mean Squared Residual (SRMR), and Root Mean Square Error Approximations (RMSEA). For each metric, the recommended strong model-fit thresholds are a CFI above 0.9, a TLI above 0.9, a SRMR less than 0.08 and/or a RMSEA less than 0.1 [33]. On the item-level, factor loading benchmarks are recommended to be greater than or equal to 0.4 [23] and are calculated by comparing each item to the appropriate factor listed in **Section 3.1**. All data analysis was performed using the SAS software [34] and R's Lavaan package version 3.5.0 [35] by two researchers to cross validate the results.

4. Results and Discussion

As previously stated, the study's results exist in two forms: (1) global metric fitting of data to the theoretical model and (2) item-level factor loadings to inform future item reduction steps. **Table 1** below characterizes the global metric fittings of CFI, TLI, RMSEA, and SRMR resulting from the CFA. The analyses for the indirect assessment instrument for Connections identified values of 0.91, 0.893, 0.07, and 0.045 for CFI, TLI, RMSEA, and SRMR, respectively. As for the indirect assessment instrument for Creating Value, the evaluated CFI, TLI, RMSEA, and SRMR were found to be 0.908, 0.896, 0.062, and 0.042. The metrics for both Connections and Creating Value all fall within acceptable limits to make claims about factor loadings [33].

Table 1. Global Data Fitting Metrics of Indirect Assessment Instruments for Connections and Creating Value

Global Data Fitting Metrics	Connections Indirect Assessment Instrument	Creating Value Indirect Assessment Instrument
Comparative Fit Index (CFI)	0.910	0.908
Tucker-Lewis Index (TLI)	0.893	0.896
Root Mean Square Error Approximations (RMSEA)	0.070	0.062
Root-Mean Squared Residual (SRMR)	0.045	0.042

The item level factor loading results from the CFA for the indirect assessment instruments (surveys) measuring Connections and Creating Value are shown in **Future studies** should continue to explore how pre-/post-data shifts the evidence of construct validity and whether these shifts are significant enough to inform the teaching praxis.

Table *2*. As previously stated in **Section 3.1**, the indirect assessment instrument for measuring Connections was hypothesized to have four factors: (1) Integrate Outside Information, (2) Consider Social, Economic, and Environmental Factors, (3) Define Connections, and (4) Make Connections within Engineering Design. Factor 1 included six observed variables (items) in which factor loadings ranged from 0.743 to 0.813. Factor 2 and Factor 3 each included three observed items. Factor 2's observed variables demonstrated exceptional results with two observed variables (CON-12 and CON-17) to be values greater than 1, indicated a strong alignment between the observed data and the hypothesized clustering of this factor. Factor 3 demonstrated relatively lower results of 0.812, 0.741, and 0.635 but all are still above the recommended threshold of inclusion (0.04). Factor 4 included six observed variables with factor loadings ranging from 0.633 to 0.891, with CON-9 demonstrating the highest factor loading of the cluster. With this, all factor loadings for the indirect assessment instrument measuring Connections fall above the recommended benchmarks in the literature, indicating a confirmation of the hypothesized factor model.

The indirect assessment instrument measuring Creating Value shared a similar story. To reiterate, Creating Value as a theoretical construct being measured was hypothesized to consist of three factors including (1) Create Value within Engineering Design, (2) Attitude and Approach Toward Value Creation, and (3) Create Value for Others. Factor 1 included 10 observed items in which all factor loadings exceeded the necessary benchmarks of inclusion and ranged from 0.807 to 0.984. The second factor's model included eight observed variables with the lowest relative factor loadings amongst the factors. The factor loadings associated with Factor 2 ranged from 0.504 to 0.893, while the range for factor loadings of Factor 3 were 0.792, 0.906, and 0.810. Given these results, all factor loadings exceed the benchmarks for inclusion meaning no necessary item reduction is directly needed according to this preliminary data analysis.

In summary, both hypothesized models for the scales measuring Connections and Creating Value performed exceptionally well from the collected first-year engineering student response data. Factor loadings all confirmed the hypothesized factors existing as subcomponents of Connections and Creating Value pedagogy. Though the scales present strong validation evidence to support the construct validity claims of both indirect assessment instruments, the study possesses limitations. First, only a singular context of FYEP student population was measured during the initial pilot study. Evidence within this study would provide sufficient justification for the appropriateness of using these indirect assessment instruments within similar first year engineering contexts; however, the intended goal of these instruments extends to all contexts capable of infusing EML into engineering curriculum. Thus, future validation studies should be conducted to explore diverse engineering classroom contexts. Second, the limitation of singular time points within each semester (administering the surveys at beginning of the first semester and at the end of the second semester). Understanding how the validation evidence would compare later within the semester would be warranted to support further claims that the use of these indirect assessment instruments as best practices. Future studies should continue to explore how pre-/post-data shifts the evidence of construct validity and whether these shifts are significant enough to inform the teaching praxis.

Table 2. Item Factor Loadings of Indirect Assessment Instruments for Connections (Left) and Creating Value (Right)

Connections

Item	Factor	Factor Loading
CON-4	Factor 1: Integrate Outside Information	0.766
CON-5		0.743
CON-8		0.813
CON-13		0.812
CON-14		0.774
CON-18		0.806
CON-2	Factor 2: Consider Social, Economic, and Environmental Factors	0.919
CON-12		1.078
CON-17		1.045
CON-7	Factor 3: Define Connections	0.812
CON-11		0.741
CON-16		0.635

Creating Value

Item	Factor	Factor Loading
CV-1	Factor 1: Create Value within Engineering Design	0.807
CV-4		0.816
CV-6		0.838
CV-7		0.833
CV-8		0.899
CV-12		0.812
CV-14		0.942
CV-19		0.748
CV-20		0.860
CV-21		0.984
CV-2		0.540

CON-1	Factor 4: Make Connections within Engineering Design	0.677
CON-3		0.676
CON-6		0.692
CON-9		0.891
CON-10		0.646
CON-15		0.633

CV-9	Factor 2: Attitude and Approach Toward Value Creation	0.504
CV-10		0.806
CV-13		0.780
CV-15		0.845
CV-16		0.613
CV-17		0.893
CV-18		0.813
CV-3	Factor 3: Create Value for Others	0.792
CV-5		0.906
CV-11		0.810

5. Conclusions and Future Work

This study has found that the indirect assessment instruments developed and tested in Autumn 2021 with first-year engineering students provided consistent results with the expansion. The promising results from this WIP bolster the efforts to expand the use of EM construct-specific assessment instruments across other institutions, implementing measures to support the development of EM with students, standardize assessments of the EM constructs, enable researchers to make comparisons across different groups and broaden the use of these instruments across various disciplines. Additional work is needed to identify crucial next steps in this project, including completing the CFA again with populations beyond first-year engineering classes. While this was the original population tested with this assessment instrument for the EFA and CFA, the assessment instrument was created with a broader population in mind. Therefore, the plan is to conduct extended testing of the instrument across multiple institutions, courses, and years. As validity can only be assessed for a specific context, it is important to complete this validation step. Current efforts are underway to find collaborators for this next step in validation testing.

6. Acknowledgement

The authors acknowledge The Kern Family Foundation's support of this work and the students for participating and completing the surveys.

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Resources

Prior validation study (EFA) - https://www.ijee.ie/1atestissues/Vol39-4/04_ijee4350.pdf

The 3Cs Indirect Assessment Instruments (Survey Example)

Connections 1 The following are statements people often use to describe themselves. Please use the scale below to indicate the degree to which these statements accurately describe you. There are no right or wrong answers.

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
7 - Completely describes me

Item Description	Rating (1 – 7)
I frequently mentally integrate technical topics, relating to one another	
I can evaluate the social, economic, and environmental benefits of a proposed solution to a problem	
I habitually assess “What if?” regarding connections between aspects of my design	
I can apply a given set of user needs as part of the design process	
I can identify needed resources or expertise to fill an identified knowledge gap	
I tend to use current affairs in discussions of technical solutions	

Creating Value 1 The following are statements people often use to describe themselves. Please use the scale below to indicate the degree to which these statements accurately describe you. There are no right or wrong answers.

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
7 - Completely describes me

Item Description	**Rating (1 – 7)**
I can justify that a proposed opportunity to create a product, process, or service can be developed to create value using research from multiple sources.	
I can identify a failure or area of improvement in a submission, project, or team environment.	
I spend time thinking about what engineering solutions are good for individuals versus society	
I regularly ask questions that reveal authentic demand	
I spend time thinking about how the value of my work is connected to human flourishing and well-being	