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Building and Revising an Assessment to Measure Students' Self-Efficacy in Systems Thinking

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Building and Revising an Assessment to Measure Students' Self-Efficacy in Systems Thinking

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Abstract

Given the growing interest in teaching systems thinking (ST) and systems engineering (SE) in traditional engineering majors (e.g., mechanical engineering), a critical goal involves creating valid and reliable methods for assessing students' development in systems thinking and systems engineering. To measure students' development, it is important to distinguish changes in students' performance from changes in their attitudes and beliefs. This paper discusses ongoing refinements to the portion of the Systems Thinking Skills Survey (STSS; Muci-Kuchler et al., 2017) that is designed to measure students' *self-efficacy* (Bandura, 1997; 2006) – i.e., belief in their capacity to apply knowledge and skills to systems engineering problems. Across multiple semesters, pre- and post-test STSS datasets from two universities were analyzed to gauge the validity and internal consistency of 44 self-efficacy items. Results guided changes to the items, while also enabling a reduction in the instrument's length. With a noticeable reduction to only 30 items, the new version showed similarly high internal consistency (as measured by Cronbach's alpha) across multiple institutions and course levels. In addition, specific subscales were identified to measure students' self-efficacy for particular systems engineering topic/skill areas, e.g., concept generation, setting target specifications, identifying customer needs, and systems architecture. Finally, results from administering the new version as a pre/post-test showed that students had significant gains in self-efficacy after taking a mechanical engineering course that incorporated systems thinking/systems engineering material, thereby demonstrating that the revised instrument is sensitive enough to detect changes in self-efficacy over time. These significant gains were present in students' overall self-efficacy ratings, as well as in their ratings for each self-efficacy subscale. Overall, these results highlight the value of iterating on assessment practices as part of curriculum development.

Background

The complexity of the products and systems that engineers design, develop, operate, support, and retire from service has increased drastically over time. In order to prepare engineering graduates to successfully engage in the different activities that occur over the life cycle of a complex product or system, students need to be exposed to systems thinking (ST) and systems

engineering (SE) concepts during their undergraduate education. This has led to growing interest in teaching ST/SE both within and outside of systems engineering courses (Bedillion et al., 2019; Cattano et al., 2010; Frank & Elata, 2005; Muci-Kuchler et al., 2017, 2019; Muller & Bonnema, 2013; Robinson-Bryant, 2018; Squires et al., 2011; Youssef & Arutyunov, 2016). In the case of majors like mechanical engineering, the goal is to have graduates who understand and can apply fundamental ST and SE concepts, not to have graduates who are system engineers per se.

When faculty in traditional engineering programs incorporate ST/SE concepts and skills into their courses, a critical goal involves creating valid and reliable methods for assessing students' development in these new areas. Developing effective assessments is not easy in general (e.g., Garfield & Gal, 2007), and doing so outside of one's disciplinary specialty (e.g., mechanical engineering faculty designing a systems engineering assessment) is even more challenging. Thus, a high-level goal of the current effort is to create, test, and refine a standardized assessment for ST/SE that can be disseminated for faculty to use as part of their teaching practice, regardless of whether their expertise is in ST/SE. An added advantage of such an instrument is that it can provide a common metric for evaluating the impact of different educational interventions that target ST/SE learning outcomes, even across institutions.

When conceiving an assessment for ST/SE, especially in the context of non-SE courses, it is important to distinguish the assessment of students' knowledge and skills – i.e., their ability to apply ST/SE concepts and skills to solve technical problems – from the assessment of students' self-efficacy related to ST/SE – i.e., their *beliefs about* their capabilities to solve ST/SE problems. Within ST/SE, prior assessment work has been conducted with a focus on the former (Frank & Kasser, 2005; Tomko et al., 2017; Zhang & Wade, 2018). While performance assessment is certainly central to measuring how well students have achieved relevant learning outcomes, the goals of ST/SE instruction may also include students' development of positive beliefs about their capabilities regarding ST/SE (see Ponton et al., 2013).

Self-efficacy is a psychological construct first posited by Bandura (1982) and defined as "judgments of how well one can execute courses of action required to deal with prospective situations" (p. 122). A large body of evidence shows that one's self-efficacy influences a variety of psychological states, choice of activities, and ultimately outcomes. For example, self-efficacy is positively correlated with motivation and performance across multiple domains (Pajares, 1996, 2003; Schunk, 1990). In STEM education, self-efficacy has been shown to predict students' choice of courses and majors (Pajares, 1996), career trajectories (Betz & Hackett, 1986), and learning outcomes (Brauner et al., 2010). That said, ratings of one's self-efficacy are not equivalent to measures of one's *actual* ability to execute a task, and various studies show that these two constructs do not always co-vary.

Self-Efficacy in Engineering and Current Project Goals

Several self-efficacy instruments have been developed and tested in other areas of engineering education. For example, Carberry et al., (2010) validated an instrument designed to measure students' self-concepts toward engineering design tasks, including their self-efficacy for engineering design. Interestingly, these researchers found that self-efficacy was positively correlated with other key educational variables, such as student motivation, further emphasizing

the importance of including self-efficacy in engineering education research. Similarly, Mamaril et al. (2016) evaluated the factor structure, validity, and reliability of several general and skill-specific measures of engineering self-efficacy. Both of these engineering self-efficacy instruments have robust demonstrations of their validity and reliability, but neither measures self-efficacy for ST/SE per se – the current paper's focus. Given that self-efficacy is often content- and context-specific, there is a need for a targeted self-efficacy instrument for ST/SE rather than using one focused on another area of engineering.

Prior work by Muci-Kuchler and colleagues (Muci-Kuchler et al., 2017, 2019, 2020; Degen et al., 2018) has involved designing and administering a targeted self-efficacy instrument for ST/SE. This instrument was used in various course contexts to measure pre/post changes in students' self-efficacy for ST/SE. It is encouraging and worth noting that in several administrations of this self-efficacy instrument, students demonstrated significant and positive change in self-efficacy after taking a mechanical engineering course that incorporated fundamental ST/SE concepts. However, there are several areas for improvement that we aim to address in the current paper. First, the validity and reliability of this original ST/SE self-efficacy instrument has not been fully tested. Moreover, even though many items in the original instrument were mapped to a specific sub-topic within ST/SE (e.g., identifying customer needs, setting target specifications, concept generation, and systems architecture), some items were mapped to "Other" (a generic category, not related to the other subtopics), and the number of items mapped to the specific sub-topics varied substantially, with some having only two items. In addition, students commented that the instrument was rather long and somewhat repetitive (multiple questions targeting the same sub-topic were worded similarly, though not identically, to assess the consistency of response). Finally, the response format included "N/A" as an option, which is not consistent with the self-efficacy ratings format suggested by Bandura (2006).

The goal of the current paper, then, is to refine the original ST/SE self-efficacy instrument to address these identified gaps while maintaining or enhancing its other measurement properties. We pursue this goal by (1) Administering the original instrument to students in introductory mechanical engineering courses at two different institutions, (2) Analyzing several properties of the instrument across these two new datasets, (3) Identifying and implementing specific adjustments to the instrument – creating a revised version – to address the issues highlighted in prior work and replicated in our latest administration, (4) Conducting analyses on the revised version of the instrument, with a focus on internal consistency and possible subscales, and (5) Administering the revised instrument in several mechanical engineering courses as a pre/post-test to re-examine its measurement statistics and to test its sensitivity to detect significant pre/post changes.

Methods

Data

In order to refine the ST/SE self-efficacy instrument, we collected data in Fall 2019 from two introductory mechanical engineering courses offered at two different institutions. The pre-test form used in that semester was based on the original self-efficacy instrument from prior work.

Based on analyses of that data (and other review of the instrument's features), a revised instrument was created during the Fall 2019 semester. We then administered the revised version of the instrument in Spring 2020 in a mechanical engineering capstone design course and in Fall 2020 in the same two introductory mechanical engineering courses as Fall 2019. The Spring 2020 and Fall 2020 data were then used to test whether and how our revisions worked to address the issues identified. In addition, the revised instrument was administered as a pre/post-test (i.e., at the beginning and end of each semester) so that we could also assess whether the revised instrument was sensitive enough to measure a change in self-efficacy across the course of a semester. See Table 1 for a list of the data sources used.

While it is not the focus of this paper, it is worth noting that all of the mechanical engineering courses in this analysis were designed so that ST/SE concepts and skills were incorporated – e.g., via various combinations of introducing these concepts in lecture and assigning homeworks, case studies and small-group projects that exercise the ST/SE concepts and skills.

Table 1. Semester and course administrations of the STSS

Semester	School	Course
Fall 2019	Institution A	Intro to Mech Eng
Fall 2019	Institution B	Intro to Mech Eng
Spring 2020	Institution A	Capstone Design
Fall 2020	Institution A	Intro to Mech Eng
Fall 2020	Institution B	Intro to Mech Eng

Analysis

The analyses we conducted to assess the original and revised self-efficacy instrument's measurement statistics include the following. First, we computed Cronbach's alpha as a measure of internal consistency for the original instrument as a whole, as well as for the subscales within the instrument (i.e., where a subscale is the set of items that were mapped to a specific ST/SE concept or sub-topic). Next, we conducted exploratory factor analysis (EFA) on the original instrument to establish the viability of using multiple subscales. Then, after revising the instrument in light of these results, we computed Cronbach's alpha on the revised instrument – both as a whole and for the newly composed subscales. And finally, we computed the pre/post-test changes in self-efficacy from the revised instrument, as administered in Spring 2020 and Fall 2020.

Results

Fall 2019 (original instrument)

In fall 2019, the original 44-item self-efficacy instrument with 5-point Likert scale (0=not at all, 1=a little, 2=moderately, 3=very, 4=completely) was administered as a pre-survey at the start of the semester in two institutions' introductory mechanical engineering courses. Using Cronbach's alpha to determine the internal consistency of items in relation to each other, the original 7-subscale instrument had a Cronbach's alpha =.98 (Table 2, middle column), above the threshold for acceptable values (Nunnally & Berstein, 1994). However, there was a desire to shorten the instrument and make the subscales more uniform in number of items, while retaining the high internal reliability.

Table 2. Fall 2019 Institution A and B Pre - Original and Revised Instrument, n=207

Overall and subscales	Original 44-item Instrument Chronbach's alpha	Revised 30-item Instrument Chronbach's alpha
Overall	.98	.98
Systems Thinking / Systems Engineering	.96	.93
Identify Customer Needs	.52	.52
Set Target Specification	.91	.91
Concept Generation	.85	.83
Concept Selection	.78	.78
System Architecture	.92	.88
Other	.90	--

Initially, an exploratory factor analysis was performed to determine the number of factors present. The Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy was .96 and Bartlett's test of sphericity was statistically significant ($x^2(946)=7537$, $p<.001$), both of which suggested that it was appropriate to proceed with the exploratory factor analysis (Dziuban & Shirkey, 1974). Based on Kaiser's rule of retaining all factors with eigenvalues greater than 1, the results suggested a 5 factor structure, which indicates that a reduction in the number of subscales is appropriate.

A closer examination of the subscales and the items resulted in the content experts proposing a revised instrument with 14 fewer items and the removal of the "other" category. A comparison of the initial and revised versions of the instrument can be found in Table 3, and sample items from the revised instrument are presented in Table 4. Reanalyzing Cronbach's alpha for the 30-item, revised instrument yielded results similar to that of the longer 44-item instrument (see Table 2, rightmost column), which further supported the decision to reduce the instrument. (This re-analysis was possible on the same dataset because the revised instrument was a subset of the original items, i.e., data from items removed from the instrument were simply removed from the analysis.)

For most of the subscales in the revised instrument, internal consistency as measured by Cronbach's alpha was fairly high and comparable to the original version. A notable exception is the Identify Customer Needs subscale (Cronbach's alpha = .52). This is not surprising given that this subscale had only two items in both the original and revised versions (see Discussion).

Table 3. STSS self-efficacy items by sub-category

Subscale	Initial Version - Number of Items	Revised Version - Number of Items
Systems Thinking/ Systems Engineering	18	10
Identify Customer Needs	2	2
Set Target Specifications	5	5
Concept Generation	6	5
Concept Selection	3	3
Systems Architecture	7	5
Other	3	0
Total Number of Items	44	30

Table 4. Revised STSS self-efficacy sample items by sub-category

Subscale	Sample Item Stem
Systems Thinking/ Systems Engineering	Identifying the boundaries and external interfaces of a product or system.
Identify Customer Needs	Assigning a relative-importance to customer needs.
Set Target Specifications	Identifying technical specifications for determining the success of a product or system.
Concept Generation	Creating solutions that balance technical and non-engineering requirements of a product or system.
Concept Selection	Developing experimental prototypes for concept evaluation.
Systems Architecture	Identifying the relationships between various components of a product or system.

Note: All items followed the same stem: How certain are you that you can apply the topics/skills mentioned below to an engineering project involving the development of a product or system?

Revised Instrument Internal Consistency

We administered the 30-item instrument across three semesters at two institutions. Table 5 depicts the internal consistency of the revised instrument disaggregated by institution. Results show a similar pattern across semesters and institutions, particularly for the freshman-level introduction to mechanical engineering courses with larger sample sizes. This suggests that in addition to demonstrating high reliability overall, the internal reliability is fairly stable with different samples of students.

Table 5. Internal consistency (measured by Cronbach's alpha) for the *revised* self-efficacy portion of the STSS, both overall and for each subscale, across five administrations.

	Cronbach's Alpha - Pre-Assessments				
	Fall 2019		Spring 2020	Fall 2020	
STSS Self-Efficacy Subscale	Inst'n A - Intro (n~85)	Inst'n B - Intro (n~34)	Inst'n A - Capstone (n~21)	Inst'n A - Intro (n~52)	Inst'n B - Intro (n~22)
Overall	.97	.98	.91	.97	.97
Systems Thinking/ Systems Engineering	.92	.95	.70	.92	.93
Identify Customer Needs	.44	.54	.63	.48	.52
Set Target Specifications	.88	.90	.61	.86	.92
Concept Generation	.82	.84	.80	.87	.77
Concept Selection	.70	.79	.56	.71	.71
Systems Architecture	.84	.89	.73	.92	.82

Revised Instrument: Sensitivity to measure change

In order to determine the sensitivity of the instrument (i.e. whether or not it could detect a change in self-efficacy following an intervention), the researchers compared pre and post self-efficacy scores for students (Figure 1). Depending on the sample size and to address violations of normality, either a paired samples t-test or the non-parametric Wilcoxon sign rank test was used. Across all five administrations of the revised instrument, students' self-efficacy was significantly higher on the post-assessment as compared to the pre, demonstrating that the revised 30-item instrument has the sensitivity to detect change in students' self-efficacy following an intervention.

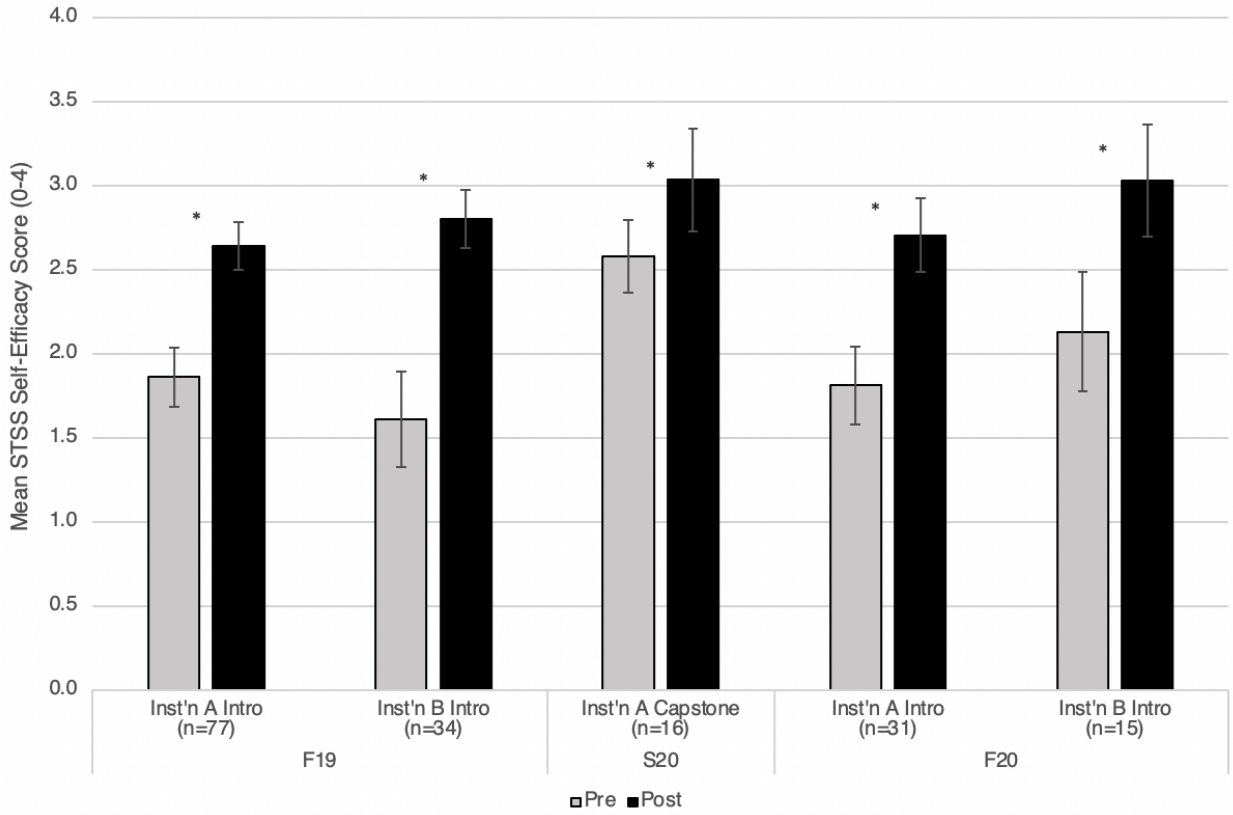

Figure 1. Comparison of Pre and Post Student Self-Efficacy Scores Across Five Administrations
**significant at the 0.01 level*

Discussion

In this research, we started with a 44-item instrument designed to measure students' self-efficacy in ST/SE. Although the instrument had been working reasonably well in prior work, we saw room for improvement. So we used analyses of the instrument's measurement properties, along with expert input, to make adjustments to the instrument. In particular, we were able to shorten the instrument to 30 items, while maintaining its overall reliability. We made these reductions in such a way that the revised instrument was a subset of the original one. Moreover, in so doing, we adjusted the subscales in the instrument – i.e., subsets of items that mapped to particular subtopics in ST/SE – to maintain more uniformity in their size and while maintaining reliability for each subscale.

Subsequent administrations of the revised instrument demonstrated that it had high reliability overall, even when administered across two different institutions and two different course levels (freshman level introduction to mechanical engineering course and advanced capstone design course). Finally, when the revised instrument was administered as a pre-/post-survey (i.e., at the beginning and end of the semester) in mechanical engineering courses that incorporated ST/SE into the instruction and assignments, we found that it was sensitive enough to detect statistically significant changes in self-efficacy.

These are all encouraging findings associated with the revised instrument. Still, further improvements can be made. First, the subscale associated with "Identify Customer Needs" had only two items in both the original and revised versions and, not surprisingly, was the subscale with lowest internal consistency. Future work could explore the advantages of various adjustments to this subscale, e.g., adding items and possibly also revising items already present. Second, the subscale structure of the revised instrument warrants further investigation. Even though the subscales show reasonable internal consistency across multiple, diverse administrations, exploratory or confirmatory factor analyses could be conducted to test the empirical basis for the subscales and additional expert input could be sought regarding the content validity of these subscales. Finally, it would be valuable to conduct further research on self-efficacy changes in ST/SE – either overall or at the subscale level – as a function of different interventions that incorporate ST/SE concepts and skills into traditional engineering courses.

In sum, the work in this paper highlights that, in addition to focusing on refining instructional interventions in engineering education research, it is equally important to bring an iterative improvement approach to the design of assessment instruments. Engineering education research benefits when both instruction *and* assessment approaches are refined based on theory and data.

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References

Bandura, A. (1982). Self-efficacy mechanism in human agency. American Psychologist. 37(2): 122–147.

Bandura, A. (2006). Guide for constructing self-efficacy scales. In F. Pajares, & T. Urdan (Eds.) *Self-Efficacy Beliefs of Adolescents* (pp. 307-337). Greenwich, CT: Information Age.

Bedillion, M. D., Lovett, C., Muci-Kuchler, K. H., & Degen, C. M. (2019). Teaching systems thinking in a capstone mechatronic design course. In 2019 ASEE Annual Conference & Exposition, number 10.18260/1-2–33355, Tampa, Florida, June 2019. ASEE Conferences.

Betz, N. E., & Hackett, G. (1986). Applications of Self-Efficacy Theory to Understanding Career Choice Behavior. Journal of Social and Clinical Psychology. 4 (3): 279–289.

Brauner, P., Thiemo, L. Ziefle, M,; Schroeder, U. (2010). The Effect of Tangible Artifacts, Gender and Subjective Technical Competence on Teaching Programming to Seventh

Graders. Teaching Fundamentals Concepts of Informatics. Lecture Notes in Computer Science. 5941. pp. 61–71.

Carberry, A. R., Lee, H., & Ohland, M. W. (2010). Measuring engineering design self-efficacy. *Journal of Engineering Education, 99*(1), 71-79.

Cattano, C., T. Nikou, & L. Klotz. (2010). *Teaching systems thinking and biomimicry to civil engineering students.* Journal of Professional Issues in Engineering Education & Practice, 137(4): p. 176-182.

Degen, C.M., et al., *Measuring the Impact of a New Mechanical Engineering Sophomore Design Course on Students' Systems Thinking Skills*, in *ASME International Mechanical Engineering Congress and Exposition,* 2018: Pittsburgh, PA.

Dziuban, C. D., & Shirkey, E. C. (1974). On the psychometric assessment of correlation matrices. *American Educational Research Journal*, *11*(2), 211-216.

Frank, M., & Elata, D. (2005). Developing the capacity for engineering systems thinking (cest) of freshman engineering students. Systems Engineering, 8(2):187–195.

Frank, M., & Kasser, J. (2005) Assessing the capacity for engineering systems thinking (CEST) and other competencies of systems engineers. In B. Cogan (Ed.) *Systems Engineering – Practice and Theory* (pp. 217-230). www.intechopen.com.

Garfield, J., & Gal, I. (1999) Assessment and statistics education: Current challenges and directions. *International Statistical Review, 67*(1), 1-12.

Mamaril, N. A., Usher, E. L., Li, C. R., Economy, D. R., & Kennedy, M. S. (2016). Measuring undergraduate students' engineering self-efficacy: A validation study. *Journal of Engineering Education, 105*(2), 366-395.

Muci-Kuchler, K.H., et al., *Incorporating basic systems thinking and systems engineering concepts in a mechanical engineering sophomore design course*, in *ASEE Annual Conference,* 2017: Columbus, Ohio.

Muci-Kuchler, K.H., et al. (2019). *Extending Systems Thinking Skills to an Introductory Mechanical Engineering Course*, in *ASEE Annual Conference.* Tampa, Florida.

Muci-Kuchler, K.H.B., Cassandra M.; Bedillion, Mark D., Lovett, Marsha; Whitcomb, Clifford;. *Incorporating Systems Thinking and Systems Engineering Concepts in a Freshman-Level Mechanical Engineering Course*. in *ASEE's Virtual Conference at Home with Engineering Education*. 2020. Virtual.

Muller, G., & Bonnema, G. M. (2013). Teaching systems engineering to undergraduates; experiences and considerations. INCOSE International Symposium , 23(1):98–111.

Nunnally, J. C., & Bernstein, I. H. (1994). *Psychometric theory*. (3rd ed.). New York, NY: McGraw-Hill.

Pajares, F. (1996). Self-Efficacy Beliefs in Academic Settings. Review of Educational Research. 66(4): 543–578.

Pajares, F. (2003). Self-Efficacy Beliefs, Motivation, and Achievement in Writing. Reading and Writing Quarterly. 19 (2): 139–158.

Ponton, M. K., Edmister, J. H., Ukeiley, L. S., & Seiner, J. M. (2001). Understanding the role of self-efficacy in engineering education, *Journal of Engineering Education, 90*(2), 247-251.

Robinson-Bryant, F. (2018). Developing a systems thinking integration approach for robust learning in undergraduate engineering courses. In 2018 ASEE Annual Conference & Exposition, number 10.18260/1-2–30294, Salt Lake City, Utah, June 2018. ASEE Conferences.

Schunk, D, H. (1990). Goal Setting and Self-Efficacy During Self-Regulated Learning. Educational Psychologist. 25, 71–86.

Setting, and Self-Evaluation. Reading and Writing Quarterly. 19(2): 159–172.

Squires, A.F., et al. (2011). *Investigating an innovative approach for developing systems engineering curriculum: The Systems Engineering Experience Accelerator*, in *ASEE Annual Conference*. American Society for Engineering Education.

Tomko, M., Nelson, J., Linsey, J., Bohm, M., & Nagel, R. (2017). Towards assessing student gains in systems thinking during engineering design. In *21st International Conference on Engineering Design (ICED17), Vol. 9: Design Education,* Vancouver, Canada, 21.-25.08.2017. pp. 179-188.

Youssef, G., & Arutyunov, V. (2016). An approach to integrating systems engineering into senior design. In 2016 ASEE Annual Conference & Exposition, number 10.18260/p.26569, New Orleans, Louisiana, June 2016. ASEE Conferences.

Zhang, P., & Wade, J. P. (2018). Automated assessment of systems engineering competencies. Proceedings of the ASEE Conference.