Validation Studies of a Questionnaire Development for Students' Engagement with Systems Thinking

Fanny Camelia, Timothy L.J. Ferris, *Senior Member, IEEE*

Abstract—The purpose of this study was to develop and validate a new theoretically-based scale to measure students' learning of systems thinking in relation to the affective domain in the context of systems engineering education. Two variant questionnaires are reported here, one using only questions constructed using positive grammar and the other using a mix of positive and negative constructs, each applied to a different sample. The first group of 186 participants completed the positive version of the questionnaire, and, the second group of 163 completed the mixed version. Construct validity was examined through exploratory factor analysis (EFA) and confirmatory factor analysis (CFA). EFA was conducted to find the factors underlying each questionnaire. CFA was conducted to confirm the better questionnaire version and to confirm the factors which underlie both versions. The results indicate that a three factor, 16 item, scale with a mix of positive and negative wording is the better instrument with which to measure students' engagement with systems thinking. The results also indicate that the three factor, 16 item construct is a better representative of both versions of the questionnaire, whether the questionnaire has only positive questions or a mix of positive and negative questions.

Index Terms—systems thinking, education, systems engineering, systems engineering education, systems engineering and theory, affective domain

I. INTRODUCTION

FOR centuries engineering was influenced by both art and science with great engineering achievements being attained by artists, philosophers and inventors rather than by technocrats or engineers [1-3]. However, in the past 200 years, science, with its reductionist approach, has significantly challenged the roles of design and creativity in engineering [1]. This science-based approach to engineering has matured largely due to its success in isolating objects from their environment, learning their behaviour under controlled conditions, designing means to maintain these conditions and providing predictable, controllable and safe products [4]. Although this approach has served society well for a while, the current complexity of systems presents significant challenges in their development [4] and has been doing so, to various extents, for several decades leading to the development of systems engineering. Thus, following the historical pattern that great engineering occurs at times when art and science merge, the new era of engineering must bridge the art–science gap in order to successfully address the difficult and complex problems facing today's engineers [1].

Systems engineering is a link that has evolved between science and art in engineering. Systems engineering focuses on both science-based approaches, and specific needs and specific designs, the primary characteristics of art [3], to develop engineered systems. It is an approach which has been developed to address the problems of providing coherent whole systems to address complex needs in situations with complex constraints, particularly spanning technological areas with no directly applicable scientific theory [5]. It involves both creative and methodical activities to define requirements, create effective solutions and manage complexity by embracing the system concept and an interdisciplinary approach through scrutinizing the lifecycle of the product [6, 7].

The increasing need to implement systems engineering principles and practices [8, 9] corresponds with a growth in demand for systems engineers which, in turn, has led to work to improve systems engineering education and training [10-14]. There is an associated interest in understanding systems thinking, as a foundation for systems engineering, including its development and measurement [1, 15]. However, there is a research gap concerning learning and measuring systems thinking in systems engineering education. Although some studies have investigated systems thinking education in other disciplines, most of those studies focused on the cognitive domain rather than the affective domain which deals with students' development towards characterization by the knowledge and skills learned. There is a limited study and suitable measurement tool available for assessing students' affective engagement with systems thinking in systems engineering education.

F. Camelia is with the Industrial Engineering Department, Ekasakti University, Padang, Indonesia, and with the School of Engineering, University of South Australia, Mawson Lakes, SA 5095 (e-mail: fanny.camelia@mymail.unisa.edu.au).

T.L.J. Ferris is with the Centre for Systems Engineering, Cranfield University, Defence Academy of the United Kingdom Shrivenham, SN6 8LA, UK, and has an adjunct position with School of Engineering, University of South Australia, Mawson Lakes, SA 5095 (e-mail: timothy.ferris@cranfield.ac.uk).

This paper describes the development of an instrument that measures students' engagement with and characterization by systems thinking. It reports and discusses the reliability and validity of two versions of the questionnaire, applied to distinct samples of the relevant population, justifies one version of the instrument as better for further use, and discusses the best representative construct for both versions of the questionnaire for further analysis.

II. LITERATURE REVIEW

A. Systems Thinking in Systems Engineering and Systems Engineering Education

Systems thinking refers to conceptual understanding or mental constructs of the system of interest that enable perception of it as an holistic entity situated in a specific environment [16]. Systems thinking involves perception and conceptualization processes that apply systems thinking rules which include: questioning the system boundary, system structure and interrelationships; adopting multiple perspectives; considering change over time (dynamic characteristics); and applying holistic and big picture thinking [17-22]; which can be enhanced by using various systems thinking methods or tools. This view of systems thinking has more in common with the work of Ackoff, Checkland and Churchman [23-25] rather than the systems science movement view that systems are real-world phenomena and our knowledge reflects this reality [26, 27].

As systems engineers do the work of perceiving and conceptualizing their system of interest they must apply systems thinking rules recursively until they obtain an internally consistent construct, which becomes the conclusion of their investigation [16, 28, 29]. The rules were grounded in their everyday thinking, but can be enhanced through regular and conscious use of the concepts. It can be further enhanced by use of a variety of systems thinking methodologies or approaches [30], including functionalist methodologies such as systems dynamics [31], interpretative methodologies such as soft systems methodology [25], or emancipatory methodologies such as critical system heuristics [32]. It also can be further enhanced by use of a variety of visualization tools such as concept maps, mind maps and systemigrams to model the system [33]. Alternatively, systems engineers can also design a new method or approach which is the most suitable to a particular system using a combination of the available methods, selected through. Thus, the best decision can be made and the best solutions can be chosen using systems engineering processes.

B. Student's Affective Engagement with Systems Thinking in Systems Engineering Education

A systems engineer needs a combination of willingness and ability to use systems thinking as a mental construct when engaging with a system at every stage of systems engineering, performing systems engineering work using the broad range of systems thinking theories and methods and judging which is appropriate to use, and when [34]. Therefore systems engineering educators must establish both the theoretical and methodological aspects of systems thinking in systems engineering students. The theory and methods of systems thinking can be taught with methods focused on the cognitive domain. These are educational methods familiar to most members of the systems engineering community, along with improvements. Since systems thinking involves perception of the world, it is affected by the beliefs, values and assumptions that people hold. It follows that the systems engineer will emotionally engage with the cognitive content in a manner influenced by their beliefs and interests, which is the reason that the affective domain becomes important [35-38].

It is desirable for graduates to have both a strong ability to do systems thinking to support their systems engineering practice and to have a strong appreciation of the value of systems thinking so that their systems engineering practice is characterized by the thoughtful application of systems thinking. Thus, one goal of systems engineering education must be the development of the student's affective engagement with the systems thinking subject matter so that the graduate demonstrates a fluent use of systems thinking concepts, structured theories and methods in their practice. The fluency and appropriate use of the systems thinking knowledge depends on commitment to the systems thinking knowledge as a valuable approach for performing work.

In the affective development it is expected that the student will naturally, routinely and intuitively use systems thinking concepts to their engineering work even when driven by a rushed perception of the problem often resulting from under near term cost and schedule pressures.

C. Systems Thinking Measurement Tools for Systems Engineering Education

Two main ways to collect data about individuals in educational research are by administering: 1) performance tests; and 2) personality measures [39, 40]. A performance test is a structured performance assessment that can be analysed to yield numerical scores. From these numerical scores, researchers can make inferences about individuals' performance based on the constructs of performance measured by the test [39]. Performance assessment is one example of a performance test. This measure evaluates students' performance by directly examining their performance on particular tasks which are designed to represent complete, complex or real-life tasks [39].

A personality measure also can yield numerical scores. In contrast to a performance test, from these numerical scores researchers can make inferences about personal characteristics, thus, differences can be inferred on individual aspects such as values, attitude, interest or personality traits [39]. These measures ask individuals to respond to items asking about their feelings, emotions or experiences [39, 40]. A common form of a personality measure is an attitude scale that can examine an individual's viewpoint or disposition toward a particular object (such as a person, a thing or an idea).

Attitudes can be measured using several procedures such as a Likert scale, a Thurstone scale or a semantic differential

scale. A Likert scale, the summated rating scale, asks individuals to rate their responses (e.g. strongly disagree, disagree, neutral, agree or strongly agree) to various statements about an object or a concept. The assumption is that each statement has the same importance or equal attitudinal value [41]. The Thurstone scale, the equal-appearing scale, requires individuals to express agreement or disagreement with a series of statements about the attitude, object or concept. In contrast with the Likert scale, the Thurstone scale assigns a weighting or attitudinal value based on expert judgments [41]. In the semantic differential scale technique, individuals rate an attitude, object or concept on a series of bi-polar contrasting adjectives (antonyms) such as fair–unfair, valuable–worthless and good–bad. These adjectives anchor the endpoints. An attitude scale in the form of a self-report measure format is considered to be the most suitable format for measuring students' affective engagement in education [42-44].

Measurement in the affective domain is less prevalent than measurement in the cognitive domain in the literature of educational research [42]. One of the early published instruments, with accompanying evidence of validity and reliability, is called the Affective Learning Scale. This self-report instrument measures students' affective learning related to their feelings about the course instructor rather than course content [42]. There are over 200 instruments designed to measure any of a variety of attitudes towards science education, but most have been used only once and only a few show satisfactory statistical reliability or validity [44]. In engineering education, Lammi [43] created a self-report questionnaire to measure students' perceptions of course delivery and pedagogy in electrical engineering laboratories. However, this instrument also focused on students' perceptions toward the teaching and learning process rather than course content. This body of prior work has addressed a different phenomenon than is the subject of our work.

Since the present researchers' interest in the affective domain concerns the engagement and internalization by the course subject matter we decided to develop a self-report instrument to measure student affect to systems thinking as the subject matter. Three options exist for obtaining an instrument to use: develop one, locate and modify one or locate and use one in its entirety [45]. For this study to assess the affective dimension, an interest inventory, Frank's self-report measure to assess Capacity for Engineering Systems Thinking (CEST) [46] was modified.

III. METHOD

We report two studies related to the development of a questionnaire intended to measure undergraduate engineering students' engagement for and characterization by systems thinking. The questions in both versions of the survey are presented in Table I. The reliability and validity of two versions of questionnaire were tested with two groups each representative of the target population. This was followed by a confirmatory study to choose the most suitable questionnaire

for the purpose and to find the more representative construct of both versions of the questionnaire.

The target population of these studies are students enrolled in a systems engineering course in an undergraduate systems engineering program, either 'systems-centric' or 'domain centric'. The students were recruited from several universities and were studying in Australia, Singapore, Indonesia and USA. This project was conducted according to the approved ethics protocol, 0000031508, University of South Australia.

A. Administration Procedure

A paper-based questionnaire was distributed to the participants in Singapore and Australia. Participants in Indonesia and the US were asked to participate in an online version implemented in Survey Monkey. As part of the ethics protocol all participants were provided with an information sheet about the project and assured of confidentiality in their invitation to participate.

Responses from the paper-based questionnaire were recorded using Microsoft Excel for Windows 2007. The spreadsheet of results and the Survey Monkey data was all exported to SPSS. SPSS for Windows version Statistics 21 and AMOS 21 were used.

B. Reliability and Validity

Reliability of an instrument concerns consistency and reproducibility when the same subject is tested under identical conditions. Reliability has two main forms: internal consistency and repeated measurement. The reliability of the scale was calculated using Cronbach's alpha coefficient. To create the instrument with high reliability the items comprising the instrument must be clear and unambiguous. Ambiguity of wording can affect reliability because a respondent may interpret the items differently at different times [41].

Another essential characteristic of an instrument is validity, the extent to which the instrument measures what it is intended to measure. Content and face validity were judged based on the logical link between the items and the objectives of the instrument [41]. Content validity is supported, but not guaranteed, through a review of the relevant literature [47]. Face validity, the appearance that the instrument is valid is supported but not guaranteed by asking respondents or experts whether the instrument looks valid [47]. Since that judgment is based on subjective logic, different people may have different opinions; resulting in no definitive conclusion [41]. A more rigorous form of validity is needed, construct validity.

Construct validity, related to theoretical knowledge of the construct to be tested, is a more sophisticated technique for establishing the validity of an instrument [41]. Construct validity was examined through Exploratory Factor Analysis (EFA) and Confirmatory Factor Analysis (CFA). EFA was used to gather information about the interrelationship among items of each version of questionnaire. It involved Principal Component Analysis (PCA) as a factor extraction method, Kaiser's criterion and Catel's scree plot to decide the number

of factors to retain and orthogonal (Varimax) rotation to simplify and clarify the data structure [48]. This analysis was conducted using SPSS 21 Factor Reduction. Whereas, CFA employed Structural Equation Modeling (SEM) which was conducted with AMOS 21. CFA was aimed to confirm the better version of questionnaire and to confirm the better construct underlying both questionnaires. A higher-order factor analysis, was also done to explain the correlation among the first-order factors in terms of a single higher-order factor.

Construct validity can be differentiated into convergent validity and discriminant validity. Convergent validity is the evidence that two items of the same construct are correlated. In contrast, discriminant validity is the evidence that two items of different constructs are uncorrelated. These validity forms were indicated by loading factors of items or correlation of each item to its factor during EFA and by examining Composite Reliability (CR), Average Variance Extracted (AVE), Maximum Shared Variance (MSV), and Average Shared Variance (ASV) in CFA [49].

C. Missing Data Analysis

Prior to analysis, missing data was identified, patterns were found and a missing data remedy was applied. The degree of randomness in the missing data was found first, before a remedy was applied [50]. If the missing data is classified as missing completely at random (MCAR), it supports the conclusion that no systematic missing data process existed [50]. Several remedies, including replacement of missing data, for the MCAR case can be employed since no potential biases exist in the pattern of missing data [50]. The SPSS Missing Values Analysis (MVA) was used to check the MCAR assumption [51].

TABLE I

QUESTIONS PRESENTED IN THE TWO SURVEYS. QUESTIONS IN THE FIRST SURVEY ARE IDENTIFIED BY S1, QUESTIONS IN THE SECOND SURVEY BY S2, AND QUESTIONS IN BOTH SURVEYS BY S1&S2.

No	Survey	Question Text		
1	S1	I prefer to deal with the systems aspects rather than the technical details.	S2	I prefer to deal with the technical details the rather than systems aspects.
2	S1&S2	When I encounter a problem I first try to find a quick answer without getting involved in the details.		
3	S1&S2	When I encounter a problem I like to use multiple viewpoints to understand and analyze it.		
4	S1&S2	I believe that the system character can only be seen when the system is together in the assembly of its parts and their interaction		
5	S1&S2	I think I am good at personal project skill and personal organization skills.		
6	S1	I prefer leading teams rather than concentrating on my technical job.	S2	I prefer concentrating on my technical job rather than leading teams.
7	S1&S2	I like to be bold and take risks.		
8	S1	I prefer to ask questions of my colleagues or other students rather than to search for the answers on my own.	S2	I prefer to search for the answers on my own rather than to ask questions of my colleagues or other students.
9	S1&S2	I enjoy using models, mind maps, rich pictures, causal loop diagrams or graphs to understand problems.		
10	S1&S2	I want to advance in both the managerial and technical engineering tracks when I work.		
11	S1&S2	It is important to me to acquire knowledge in engineering fields other than my main field of study (e.g. Electrical/Mechanical/etc. Engineering.).		
12	S1&S2	It is important for me to learn from the differences between the expected and actual outcomes of action and change my action to improve results.		
13	S1	I like to understand the whole system structure including the system entities, their relationships, the system hierarchy and boundary.	S2	I do not like to understand the whole system structure including the system entities, their relationships, the system hierarchy and boundary.
14	S1&S2	It is important for me to identify the benefit derived from the combination of elements and actions of the system.		
15	S1	When I work in a group project (assignment) I like to see how the parts for which I am responsible function as a part of whole project rather than to concentrate only on my tasks.	S2	When I work in a group project (assignment) I like to concentrate only on my tasks rather than to see how the parts for which I am responsible function as a part of whole project.
16	S1&S2	When I work in a group project (assignment) I value the contributions that the other students contribute to completing the whole task.		
17	S1	When I contribute to a group project (assignment) I always look at the interconnections and mutual influences between the main tasks and the peripheral task and how my part interacts with and contributes to the whole task.	S2	When I contribute to a group project (assignment) I never have interest to look at the interconnections and mutual influences between the main tasks and the peripheral task and how my part interacts with and contributes to the whole task.
18	S1&S2	When I contribute to a group project (assignment) I like to be proactive rather than just accept what has been decided by others.		
19	S1&S2	When I contribute to a group project (assignment) I work hard to maintain communication with others involved.		
20	S1	When I contribute to a group project (assignment) I prefer to test the available alternative solutions and then recommend the best choice rather than to let others choose the preferred alternative.	S2	When I contribute to a group project (assignment) I prefer to let others choose the preferred alternative rather than to test the available alternative solutions and then recommend the best choice.
21	S1&S2	When I contribute to a group project (assignment) I think continuously about what can be improved rather than concentrating on my goal alone.		
22	S1&S2	When I contribute to a group project (assignment) I enjoy reviewing the whole and giving feedback to my group.		
23	S1	I see dealing with trade-off considerations (an exchange of one thing in return for another) as part of my engineering role.	S2	I do not see dealing with trade-off considerations (an exchange of one thing in return for another) as part of my engineering role.
24	S1&S2	I believe that I will enjoy finding out and analyzing the customer or market need for a system and 'translating' the needs into technical specifications for products or systems.		
25	S1	I am interested in the activities of others who contribute other discipline of knowledge in system development projects.	S2	I am not interested in the activities of others who contribute other discipline of knowledge in system development projects.
26	S1&S2	I am interested to know how the product or system I am working will function in practice.		
27	S1	I am interested in knowing how the final product or system produced by a project will be supported and maintained.	S2	I am not interested in knowing how the final product or system produced by a project will be supported and maintained.
28	S1	I believe that I will enjoy participating in strategic planning that decides future directions.	S2	I believe that I will not enjoy participating in strategic planning that decides future directions.
29	S1&S2	If I need to make any change in a part or process for which I am responsible I will check the engineering and non-engineering consequences of the change.		
30	S1&S2	In my opinion an engineering design should take into account internal organizational and external political, economic and social considerations in addition to technical considerations.		

IV. RESULTS

A. First Study

1) Questionnaire Development

Frank's work was developed to distinguish individual engineers based on their characterization for approaching systems engineering activities using systems thinking. It is concerned with the internalization with the systems thinking in a manner influenced by engineers' beliefs and interests. However, since Frank's instrument was developed for use by professional engineers with some work experience, it was modified to suit undergraduate engineering students. Furthermore, Frank's instrument only covered parts of the systems thinking aspects to be applied when engaging with an engineering system (see Section II.A). Therefore, a new instrument was developed by adding items to Frank's original instrument to address other systems thinking aspects.

The reworked questionnaire uses a seven point Likert scale for each item rather than Frank's dichotomous scale. This allows participants to reflect their true feelings between two extremes. Seven response categories were provided: 'very untrue' (1), 'untrue' (2), 'somewhat untrue' (3), 'neutral' (4), 'somewhat true' (5), 'true' (6) and 'very true' (7).

2) Sample Demographic

The first study comprised 186 undergraduate engineering students enrolled in a systems engineering course in one of four universities. Some were enrolled in each of systems-centric and domain-centric programs, 76% were male, 24% female, and average age was 25.5 years. The distribution of participants was 26 (14%) from Australia, 50 (27%) from Singapore, 52 (28%) from US and 58 (31%) from Indonesia. 46% of participants were part time students, 52% full time students, and the rest (3%) did not give their status. Further, 22% work part time, 45% full time and the others were not working.

3) Missing Data Analysis

Prior to data analysis, a missing data analysis was conducted by examining the missing data pattern and implementing a missing data remedy. A significant value indicates the data are not MCAR [51]. Since no significant difference was found ($\chi^2 = 153.009$, $df = 144$, $sig = 0.286$), the missing data can classified as MCAR. Therefore, missing data remedies can be applied.

Missing variable values were addressed by substituting with the mean value of that variable based on all valid responses. This resulted in replacing six missing values in a matrix 186 x 30 (= 5,400) data items. The total number of replaced missing values was therefore 0.11% of the total dataset.

4) Basic Descriptive Statistics

Table II provides a descriptive statistical summary of the questionnaire results. Overall, participants have valued system thinking aspects in their experience as developing engineers by showing a positive attitude when engaging with systems thinking.

TABLE II
DESCRIPTIVE STATISTICS OF THE RESULTS OF BOTH SURVEYS

	Study 1						Study 2					
Item	Min	Max	Mean	Standard Deviation	Skewness	Kurtosis	Min	Max	Mean	Standard Deviation	Skewness	Kurtosis
1	1.00	7.00	4.710	1.392	-0.550	-0.286	1.00	7.00	3.420	1.369	0.419	0.087
2	1.00	7.00	4.038	1.609	-0.022	-1.020	1.00	7.00	4.049	1.6017	-0.117	-0.751
3	1.00	7.00	5.516	1.126	-1.006	1.353	1.00	7.00	5.377	1.1386	-0.961	1.230
4	1.00	7.00	4.929	1.399	-0.675	-0.104	1.00	7.00	4.636	1.2946	-0.347	-0.360
5	1.00	7.00	5.323	1.245	-0.821	0.818	2.00	7.00	4.932	1.2076	-0.145	-0.552
6	1.00	7.00	4.710	1.529	-0.381	-0.731	1.00	7.00	3.753	1.5278	0.089	-0.617
7	1.00	7.00	4.935	1.386	-0.425	-0.460	1.00	7.00	4.821	1.3784	-0.489	-0.162
8	1.00	7.00	4.222	1.542	-0.217	-0.664	1.00	7.00	3.482	1.4999	0.203	-0.703
9	1.00	7.00	4.892	1.459	-0.455	-0.500	2.00	7.00	4.784	1.3413	-0.281	-0.627
10	1.00	7.00	5.801	1.180	-1.303	2.340	1.00	7.00	5.494	1.3619	-0.952	0.970
11	2.00	7.00	5.371	1.166	-0.594	0.027	1.00	7.00	5.265	1.3462	-0.788	0.437
12	1.00	7.00	5.586	0.995	-0.723	1.381	2.00	7.00	5.438	1.0360	-0.457	-0.204
13	1.00	7.00	5.419	1.188	-0.763	0.673	1.00	7.00	4.827	1.3452	-0.357	-0.511
14	1.00	7.00	5.462	1.061	-0.985	2.338	2.00	7.00	5.173	1.0279	-0.423	0.134
15	1.00	7.00	5.559	1.139	-1.091	1.606	1.00	7.00	4.901	1.5162	-0.508	-0.656
16	1.00	7.00	5.892	1.024	-1.280	3.005	1.00	7.00	5.500	1.2729	-1.009	1.192
17	2.00	7.00	5.516	1.056	-0.849	1.000	1.00	7.00	5.044	1.5883	-0.747	-0.198
18	2.00	7.00	5.538	1.106	-0.726	0.560	1.00	7.00	5.112	1.3100	-0.727	0.085
19	2.00	7.00	5.710	0.987	-1.024	1.970	1.00	7.00	5.494	1.1706	-0.955	1.047
20	1.00	7.00	5.242	1.190	-0.499	0.036	1.00	7.00	4.143	1.4608	0.049	-0.434
21	3.00	7.00	5.392	1.071	-0.250	-0.571	1.00	7.00	5.298	1.1698	-0.791	0.631
22	2.00	7.00	5.360	1.160	-0.528	0.003	1.00	7.00	5.225	1.2220	-1.038	1.233
23	2.00	7.00	5.366	1.103	-0.643	0.198	1.00	7.00	4.400	1.4063	0.039	-0.530
24	1.00	7.00	5.188	1.205	-0.500	0.362	1.00	7.00	5.075	1.2889	-0.596	0.198
25	1.00	7.00	5.492	1.144	-0.855	0.669	1.00	7.00	4.981	1.3765	-0.584	0.092
26	1.00	7.00	5.892	1.008	-1.350	3.361	2.00	7.00	5.869	1.0069	-1.053	1.504
27	1.00	7.00	5.634	1.108	-1.284	2.799	1.00	7.00	5.381	1.4310	-1.043	0.690
28	1.00	7.00	5.656	1.125	-.925	1.669	1.00	7.00	4.981	1.5455	-0.496	-0.492
29	2.00	7.00	5.452	1.110	-0.488	-0.375	2.00	7.00	5.313	1.0897	-0.508	-0.343
30	1.00	7.00	5.634	1.118	-0.671	0.458	1.00	7.00	5.540	1.2373	-1.460	3.043
Mean Score (*n*=186)			5.532	1.198	-0.729	0.731	Mean Score (*n*=163)		4.924	1.3190	-0.534	0.181

5) Reliability and Validity

The Cronbach's alpha obtained in this study is 0.907 which indicates excellent internal consistency [52], showing high interrelatedness of the questionnaire items.

The content validity of this questionnaire is supported by the items being based on finding from the literature review of issues related to students' affective learning of systems thinking in systems engineering, including Frank's interest inventory for assessing CEST [46]. The discussion of EFA, below, addresses the matter of construct validity.

6) Exploratory Factor Analysis (EFA)

Prior to commencing Principal Component Analysis (PCA), the suitability of data of 30 items of the scale for factor analysis was assessed by examining the correlation matrix. Inspection of the inter-item correlation matrix revealed that 320 of 435 correlations or 73% are significant at the 0.01 level. Furthermore, 173 of 435 correlations or 40% present a

coefficient of greater than 0.3. This provides an adequate basis for proceeding to the next process.

Some inter-item correlations have negative values, which is potentially incorrect because all items are positive attitude items and, therefore, all inter-item correlations should be positive. It was decided to exclude three items (items 2, 4, and 8) which have negative inter-item correlation and would increase the alpha coefficient by their removal, before finding the Kaiser-Meyer-Olkin Measure of Sampling Adequacy and Bartlett's Test of Sphericity.

Initial analysis of PCA factor extraction was performed to obtain eigenvalues for each component. Following accepted practice [53] items with cross-loadings >0.4 were excluded one at time and the factor analysis repeated with the goal of achieving a simple structure with each item loaded to a single factor at >0.4. Five components emerge from the Kaiser criterion, each with an eigenvalue exceeding 1. An inspection of the Catel's scree plot, revealed the inflexions that justify retaining five components. To aid the interpretation of these five components, orthogonal (Varimax) rotation was performed to it load a smaller number of variables onto each factor resulting in easier interpretation of the factors [54]. The rotated solution showed a simple structure, with five components showing a strong loadings and all variables loading substantially to one component.

Table III shows the simple structure achieved after the exclusion of five items that either loaded onto no factor, or cross-loaded at >0.4 and were considered factorially impure [55]. Most items have loadings rated as at least 'good' [55]. Items, 3, 12, 25, 29 had low loading factors (<0.50), which is considered not significant, thus indicating a convergence validity issue [50]. Those items do not correlate strongly within their factor. Two of them, 12 and 25, also had cross-loadings which differ by less than 0.2 [56] which indicate discriminant validity issues.

This process resulted in a simple structure questionnaire, with 5 factors and 22 items (M1). Factor 1 has nine items, factor 2 has four items, and factors 3, 4 and 5 have three items each. Cronbach's alpha coefficients were calculated for the five subscale. The coefficient alphas for the five subscales were 0.858, 0.773, 0.725, 0.716 and 0.640 for Factors 1 to 5 respectively. Although, the alpha coefficient of Factor 5 is a little weak, all were well within the acceptable range [50].

TABLE III
SUMMARY OF EXPLORATORY FACTOR ANALYSIS RESULTS FOR STUDY 1 LEADING TO MODEL 1 AND INTERPRETATION OF THE FIVE COMPONENTS QUESTION NUMBERS ARE AS DEFINED IN TABLE I

Question	Rotated Factor Loadings					Interpretation
	1	2	3	4	5	
28	**0.660**	0.161	0.253	0.147	0.337	Inclination towards
24	**0.653**	0.327	-0.018	0.002	0.348	taking holistic view
27	**0.648**	0.174	0.125	0.272	0.029	and interest in the
11	**0.645**	0.175	0.087	-0.068	-0.035	activities of
23	**0.641**	-0.113	0.098	0.300	0.124	specialists in other
29	**0.488**	0.345	0.331	0.176	0.204	areas
3	**0.423**	0.206	0.343	0.214	0.232	
25	**0.419**	0.330	0.350	0.266	0.234	
12	**0.405**	0.281	0.348	0.388	0.059	
20	0.177	**0.715**	0.227	-0.056	0.017	Interest in ensuring
21	0.126	**0.712**	0.363	0.153	0.100	system coherence
18	0.112	**0.644**	0.014	0.365	0.216	
22	0.319	**0.618**	0.150	0.260	0.066	
9	0.048	0.087	**0.775**	0.027	0.126	Interest in and
14	0.212	0.238	**0.665**	0.275	0.053	enjoyment of using
13	0.301	0.339	**0.653**	0.180	0.044	system modeling methods
16	0.214	-0.009	0.312	**0.801**	0.015	Perception of
19	0.057	0.361	-0.024	**0.688**	0.177	interconnectedness
17	0.311	0.241	0.291	**0.521**	0.150	of work tasks done in a team
6	0.203	0.148	-0.129	0.175	**0.735**	Inclination to
1	0.154	-0.004	0.168	-0.090	**0.731**	teamwork and
5	0.030	0.120	0.225	0.208	**0.698**	organization
Eigenvalue	7.960	1.585	1.247	1.166	1.113	
% variance	36.184	7.206	5.667	5.300	5.059	
Alpha coefficient	0.858	0.773	0.725	0.716	0.640	

B. Second Study

1) Questionnaire Development

In the second study, we reversed the wording, and scoring, technique for some items in the questionnaire. The aim was to prevent 'response sets' and to encourage careful reading of items. A 'response set' is the tendency for a participant to respond to a series of items in a specific direction, regardless of item content [40]. Response sets include 'acquiescence', a tendency to say 'yes', 'true' or 'agree' rather than 'no', 'untrue' or 'disagree' on a series of items. Another response set is the 'socially desirable response set', the tendency to provide socially desirable answers.

Both types of response sets are likely if the questionnaire wording is grammatically positive throughout. Participants may consistently give similar answers for most questions, or the students may acknowledge that 'systems thinking' is 'important', but with lack of understanding. The items with reversed wording are marked with 'S2' in Table I. All other items remain the same as in study one. The score of items with reverse wording is reversed before analysis.

2) Sample Demographic

In the second study there were 163 enrolled in a systems engineering course in the same four universities. 88% were male and 12% female, with an average age of 26.95 years. The distribution of participants was 91 (56%) from Australia, 59 (36%) from Singapore and 13 (8%) from the US. 42% were part-time and the rest full-time students. 20% of participants work part-time, 40% full-time and the remainder were not working.

3) Missing Data Analysis

Again we performed a missing data analysis and missing data remedy process as we did in the first study. No significant difference was found in this study ($\chi^2 = 45.431$, $df = 39$, $sig = 0.222$). Therefore, the missing data is classified as MCAR and missing data remedies were applied. Again, mean substitution was used to generate replacement values for the missing data [50]. This resulted in a total of 51 replaced missing values in a matrix 163 x 30 (= 4,890) data items. The total number of replaced missing values was therefore 1.04% of the full dataset.

4) Reliability and Validity

The Cronbach's alpha obtained in this study was 0.837. This indicates very good internal consistency [52]. This coefficient was slightly lower than in the first study (0.907). This was potentially caused by the reverse wording technique applied to some items. It is believed that the reliability reduction results from a reduction in response sets and that the benefit of reducing response set effects more than offsets the lower, apparent, reliability [40]. Construct validity, which indicates the extent to which the tool measures a theoretical construct, is examined through the EFA processes as for the first study.

5) Basic Descriptive Statistics

Table II summarizes the descriptive statistics for the 163 respondents' scores on the thirty items of questionnaire. As in the first study, participants have valued aspects of systems thinking while engineers in education by showing a positive attitude when engaging with systems thinking.

6) Exploratory Factor Analysis (EFA)

Similarly as in the first study the suitability of the data for factor analysis was assessed by examining the correlation matrix. Inspection of the inter-item correlation matrix revealed that 167 of 435 correlations, 38%, are significant at the 0.01 level. Furthermore, 86 of 435 correlations or 19.77% present a coefficient of greater than 0.3. This provides an adequate basis for proceeding to the next process.

Several inter-item correlations (questions 1, 2, 3, 4, 5, 7, 8, 9, 14 and 20) have negative values, which is potentially incorrect because, after reversing the scores of items with reversed wording, all inter-item correlations should be positive. The number of items with negative correlation is high (30% of the total), and may have been caused by the wording reversal confusing respondents, although only three of these items had reversed wording. Thus, we decided to exclude items with negative correlation before performing the Kaiser-Meyer-Olkin Measure of Sampling Adequacy and Bartlett's Test of Sphericity.

Four components emerge from the analysis using the Kaiser criterion, which retained all the components with an eigenvalue exceeding 1. However, the inspection of the Catel's scree plot revealed inflexions that would justify retaining only three components. We chose to retain 3 components since Table IV shows the simple structure that was achieved after the exclusion of the two items (6 and 10) associated with the fourth factor. To aid the interpretation of these three components, orthogonal (Varimax) rotation was performed.

The eigenvalues and variance shown in Table IV satisfy typical criteria for a meaningful and interpretable simple structure. These criteria are a minimum of three items in each

factor; and that the majority of items in the structure have loadings; >0.55 (good) [55]. All items in the structure have loadings more than 0.5 which are rated highly (>0.7 excellent; >0.63 very good; >0.55 good; >0.45 fair) [55]. All items also had cross-loading which differ by more than 0.2. These are evidence for both convergent and discriminant validity.

TABLE IV
SUMMARY OF EXPLORATORY FACTOR ANALYSIS RESULTS FOR STUDY 2
LEADING TO MODEL 2 AND INTERPRETATION OF THE THREE COMPONENTS,
QUESTION NUMBERS ARE AS DEFINED IN TABLE I

Question	Rotated Factor Loadings			Factor	Interpretation
	1	2	3		
25	**0.804**	0.077	0.184	1	Preference or inclination
27	**0.777**	0.191	0.050	1	towards whole of system
17	**0.771**	0.089	0.017	1	perspectives
28	**0.749**	0.097	0.052	1	
15	**0.723**	0.019	0.131	1	
13	**0.697**	0.102	0.026	1	
29	0.084	**0.839**	0.108	2	Interest in the intended
30	-0.007	**0.697**	0.194	2	purpose or application of
24	0.201	**0.664**	0.201	2	the whole system under
26	0.318	**0.660**	0.190	2	consideration or
12	0.032	**0.605**	0.348	2	development.
21	0.059	0.200	**0.705**	3	Inclination towards and
11	0.085	0.043	**0.654**	3	participation in seeking a
18	0.024	0.147	**0.607**	3	coherent, whole, system
16	0.202	0.312	**0.560**	3	solution.
22	0.052	0.322	**0.559**	3	
Eigenvalue	4.951	2.533	**1.122**		
% variance	30.954	15.833	**7.015**		
Alpha coefficient	0.857	0.789	**0.673**		

The EFA process in the second study resulted in a simple structure comprising 16 items distributed to three factors (M2). Factor 1 has six items, and factors 2 and 3 have five each. Cronbach's alpha coefficients were calculated for the three subscales. The coefficient alphas for the three subscales were 0.857 for Factor 1, 0.789 for Factor 2, and 0.673 for Factor 3. Again, the alpha coefficient of Factor 3 is a little weak, but all these values are acceptable for an exploratory study [50].

C. Confirmatory Study

In brief, by comparing convergent validity and discriminant validity of both structures we conclude that the second version with reverse wording with the second structure (M2) is better in identifying the factors underlying the questionnaire. This conclusion can be evaluated by a confirmatory analysis, done either by splitting the original data set or using a separate sample [50].

To confirm that M2, resulting from the second study is a better fit than M1, from the first study, and thus, the superiority of the second, reverse worded, version of the questionnaire, both structures were tested using their original data set in a CFA using SEM. The better model fit, with better convergent and discriminant validity is considered the more suitable questionnaire.

Although the first questionnaire used positive wording only and the second mixed positive and negative wording it was hypothesized that both used the same underlying constructs. Therefore, the two data sets were tested in the other derived construct, with appropriate inversion of responses to the

reversed questions. The goal was to determine which construct provided the best fit for both questionnaires.

The model validation procedure was completed by comparing the preferred, better-fitting, first-order model with its single-factor higher-order model. Results are shown in Table V.

Fit indices, including absolute, incremental and parsimonious fit measures were used in this analysis. Absolute fit measures, likelihood ratio chi-square (χ^2) statistic, the goodness-of-fit statistic (GFI) and the root mean square error approximation (RMSEA) were used to determine the degree to which the model predicts the observed covariance and correlation matrix [50]. Tucker-Lewis Index (TLI) and comparative fit index (CFI), the incremental fit measures, were used to compare the proposed model to a baseline model, usually called the null model [50]. A null model in which all variables are uncorrelated is the most common baseline model [57]. Further, parsimonious fit, adjusted goodness-of-fit index (AGFI) and the normed chi-square measures relate the goodness-of-fit of the model to the number of estimated coefficients required to achieve the level of fit [50].

TABLE V
SUMMARY OF FIT INDICES OF CFA

Model	χ^2	df	p	GFI	RMSEA	TLI	CFI	AGFI	χ^2/df
M1: 5 Factors, 22 questions, Study 1 dataset	312.597	199	0	0.871	0.056	0.912	0.924	0.836	1.571
M2: 3 Factors, 16 questions, Study 2 dataset	142.914	101	0.004	0.904	0.051	0.937	0.947	0.871	1.415
M1: 5 Factors, 22 questions, Study 2 dataset	662.233	199	0	0.640	0.120	0.461	0.540	0.543	3.328
M2: 3 Factors, 16 questions, Study 1 dataset	248.454	101	0	0.858	0.089	0.856	0.879	0.808	2.460
M3: Higher order, 3 Factors, 16 questions, Study 2 dataset	145.488	103	0.004	0.903	0.050	0.938	0.947	0.871	1.413

1) Comparison of Both Structures with Original Datasets

When comparing the model fit of M1 and M2 to its original data, Table V, we conclude that second model (M2) had a better fit index with the second questionnaire version because:
1. M2 had a lower chi-square value, although the non-significant level was not achieved (0.005). The chi-square statistic is sensitive in different ways to both small and large sample sizes. Thus other measures of fit should also be used [50].
2. M2 had the higher goodness-of-fit (GFI: 0.904). Although no absolute threshold levels for acceptability have been established, higher values indicate better fit [50].
3. M2 had the lowest root mean square error of approximation (RMSEA: 0.051). It is recommended that RMSEA less than 0.05 is considered indicative of close fit [58, 59].
4. M2 had the higher Tucker-Lewis Index (TLI: 0.937) and comparative fit index (CFI: 0.947), both of which are more than 0.9 [50, 59] and closer to 0.95 [57]
5. M2 had the higher adjusted goodness-of-fit index (AGFI: 0.871) close to the recommended level, 0.90 [50].
6. M2 had the lowest normed chi-square (χ^2/df: 1.415), which is less than 2 [59], where a large value of chi-square relative to degree of freedom signifies that the observed and estimated matrices differ considerably [50]. Combined with AGFI, this result allows conditional support to be given for the model parsimony [50].

Measures to establish discriminant validity and reliability convergence in CFA were calculated. These include Composite Reliability (CR), Average Variance Extracted (AVE), Maximum Shared Variance (MSV), Average Shared Variance (ASV) and correlations between factors in each construct [49]. These measures are provided in Table VI and Table VII. Both constructs have convergent and discriminant validity issues. However, the second model (M2) had better reliability and validity compared to M1, because:
1. CR, an indicator for reliability should be greater than 0.7. Both constructs have a factor with CR less than 0.7. However, Factor 3 of M2 was close to the threshold, thus it was not seen as a major issue.
2. EVA and CR are indicators for convergent validity. Convergent validity is demonstrated when EVA values are greater than 0.50 and CR exceeds EVA. 33.33% of factors in M2 have EVA values above the recommended threshold, which is higher than the 20% of factors in M1 with EVA values greater than 0.50. All CR values of both constructs are greater than EVA.
3. MSV and ASV, indicators of discriminant validity, should be less than AVE. 33.33% and 66.67% of factors in M2 have MSV and ASV greater than AVE. No factor in M1 has MSV less than AVE, and only 20% have ASV less than AVE.
4. Correlation coefficients, other indicator of discriminant validity, as very high correlations would suggest that factors in each constructs are measuring the same things. About 50% of correlation coefficients of M1 higher than 0.500, meanwhile 33% of correlation coefficients of M2 higher than 0.500.

TABLE VI
RELIABILITY AND VALIDITY CFA MODEL 1 AND MODEL 2

	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
M1 CR	0.860	0.780	0.760	0.719	0.641
M1 AVE	0.411	0.475	0.524	0.464	0.375
M1 MSV	0.5929	0.5476	0.5625	0.5929	0.4225
M1 ASV	0.5314	0.4360	0.6225	0.6575	0.4925
M2 CR	0.859	0.795	0.681		
M2 AVE	0.506	0.439	0.304		
M2 MSV	0.1444	0.5621	0.5621		
M2 ASV	0.13	0.3534	0.3390		

TABLE VII
CORRELATION BETWEEN FACTORS MODEL 1 AND MODEL 2

	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
Factor 1	1	0.615	0.580	0.596	0.468
Factor 2		1	0.534	0.532	0.331
Factor 3			1	0.488	0.264
Factor 4				1	0.333
Factor 5					1
Factor 1	1	0.308	0.225		
Factor 2		1	0.557		
Factor 3			1		

Correlation is significant at the 0.01 level (2-tailed).

Based on the convergent and discriminant validity examination in the previous EFA, confirmed by fit indices for convergent and discriminant validity testing in the CFA, we conclude that the evidence for the construct validity of M2 is greater than for M1. Therefore, the second instrument is more appropriate to measure students' effective engagement with the systems thinking concepts and application in engineering.

2) Comparison of Both Structures with Crossed Datasets

When comparing the fit of M1 to the second study data and M2 to the first study data, Table V, it is clear that M2 had better fit indices to the first study data because:

1. M2 two had the lower chi-square values, although the non-significant level was not achieved (0.005).
2. M2 had the higher goodness-of-fit (GFI: 0.858).
3. M2 had the lower root mean square error of approximation (RMSEA: 0.089).
4. M2 had the higher Tucker-Lewis Index (TLI: 0.856) and comparative fit index (CFI: 0.879).
5. M2 had the highest adjusted goodness-of-fit index value (AGFI: 0.808).
6. M2 had the lowest normed chi-square (χ^2/df: 2.460)

The conclusion is that three factor construct that emerged from study two is better than five factor construct that emerged that from study one, regardless of whether the reversed questions were used.

*3) Comparison: Chosen Model (M2) and Higher-order Model*

Only the first-order factors were assumed to be correlated in the factor analysis examined above. This model assumed that although the factors correlated, they are separate constructs. Therefore, an additional perspective on the factor analytic structure can be gained with the introduction of a higher-order model, knowns as the second-order factor model [50]. A second-order factor model posits that the first-order factors estimated are actually sub-dimensions of a broader and more encompassing construct, which is the student's affective engagement with systems thinking.

The model validation technique we used was to compare the preferred first-order model, M2, with a single higher-order model, M3, the hierarchical model which is nested under the three first-order factors [60]. If the fit of a higher-order model is identical, or very similar, to the fit of the corresponding first-order model, the acceptance of the higher-order model has been justified [59-61].

Table V shows that M2 and M3 had nearly identical fit which supports acceptance of the hierarchical model. This result supports that students' systems thinking in the affective domain could be conceptualized along three more specific

dimensions, which are part of a higher-order or general dimension. The conceptualization of these constructs is provided in Figure 1.

FIGURE I
MODEL 3 REPRESENTING A SINGLE HIGHER-ORDER FACTOR AND THREE FIRST-ORDER FACTORS
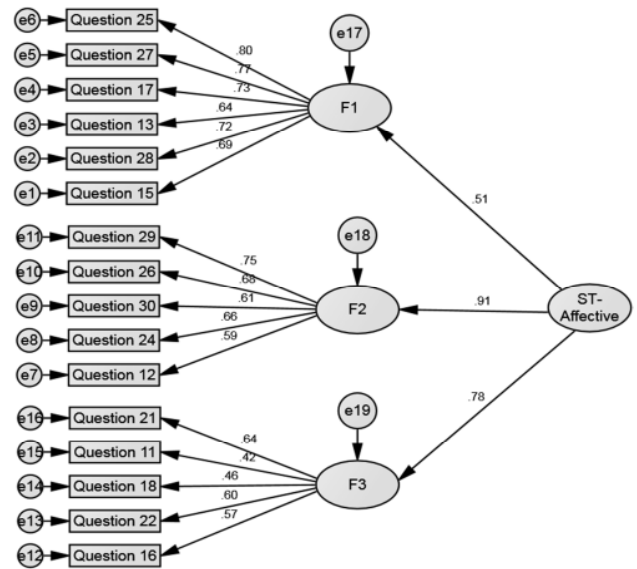
D. Face Validity of the Question Wording Reversal

The difference between the two studies was that in the second some questions were reversed in form. The question arises as to whether the changes in the form of the question may have resulted in the question not being a true inverse of the positive form, therefore resulting in contributing to a different factorization. We review the reversed questions in Table I in Table VII.

The reversal of six questions in study two resulted in five cases where the change of a verb results in a non-inverse connotation arising because of the shift from a positive form with a gentle agreement connotation to a negative form which appears absolute. The consequence is that the attempted reversal has resulted in some change of meaning of the original question which makes it inappropriate to directly substitute an inverted reading of the score. In addition, these six question are all aggregated to identify one factor, Table IV.

E. Interpretation of the Factors Identified

The acceptance of M3 (which is based on M2) supports that students' systems thinking in the affective domain could be conceptualized along three dimensions:

1. Preference or inclination towards whole of system perspectives;
2. Interest in the intended purpose or application of the system under consideration or development; and
3. Inclination towards and participation in seeking a coherent, whole, system solution.

These three dimensions, while different, are quite similar and can be represented as the natural structure of systems thinking literature as being theoretical, methodological and

practical. They reflect a construct similar to Kline's organisation of an academic discipline [62] and Checkland's summary of research elements [63]. These three factors can also be interpreted in the systems engineering context as: an individual's inclination towards systems thinking as a way of thinking about the world; an owner or user community focus in relation to performing systems engineering work; and interest in and willingness to work towards a coherent whole deliverable. Thus, this construct also distinguishes three foci of systems engineering and measures the interest or inclination of the student towards each of those foci that are therefore suitable to measure students' systems in systems engineering education.

V. DISCUSSION AND CONCLUSION

This paper reports and discusses The psychometric properties of two variant questionnaires were reported, one using only questions constructed using positive grammar constructions and the other using a mix of positive and negative constructions. Each variant was applied to a different sample. The first sample of 186 participants completed the positive version of the questionnaire, and the second sample of 163 completed the mixed version.

The EFA was used to explore the factors underlying each questionnaire. Whereas, CFA plays a role to confirm the best version of the questionnaire in order to justify one version of the instrument as better for further use. CFA also confirms the factors which fit the underlying intentions in both version of the questionnaire, and whether it has reversed wording or not. This provides the best representative construct of both versions of the questionnaire for further analysis.

The outcome is a three-factor, 16-item, multidimensional scale with some items having reversal wording which emerged from the second survey has constructs with better fit indices and construct validity compared to a five-factor, 22-item, multidimensional questionnaire used in the first survey which did not involve any items with reversal wording. This suggests that the 16-item, multidimensional scale with some items having reversal wording is the most suitable scale to measure students' affective engagement with systems thinking and supports the view that the scale may be useful for further use. This instrument can be used further to investigate students' affective engagement with systems thinking investigation over a longer period of time, such as the entire extent of a degree program. This instrument also can be used to evaluate the effectiveness of an systems engineering course in developing students' affective engagement with systems thinking during the course.

TABLE VII

ANALYSIS OF THE QUESTIONS IN SURVEY 1 WHICH WERE REVERSED IN FORM IN SURVEY 2 AND FORM PART OF THE 16 QUESTION CONSTRUCT

No	Question Text		Remarks
13	I like to understand the whole system structure including the system entities, their relationships, the system hierarchy and boundary.	I do not like to understand the whole system structure including the system entities, their relationships, the system hierarchy and boundary.	The verb "like" c.f. "not like" has a non-inverse connotation.
15	When I work in a group project (assignment) I like to see how the parts for which I am responsible function as a part of whole project rather than to concentrate only on my tasks.	When I work in a group project (assignment) I like to concentrate only on my tasks rather than to see how the parts for which I am responsible function as a part of whole project.	Reversal appears neutral.
17	When I contribute to a group project (assignment) I always look at the interconnections and mutual influences between the main tasks and the peripheral task and how my part interacts with and contributes to the whole task.	When I contribute to a group project (assignment) I never have interest to look at the interconnections and mutual influences between the main tasks and the peripheral task and how my part interacts with and contributes to the whole task.	The use of extrema "always" and "never" results in these not being inverses.
25	I am interested in the activities of others who contribute other discipline of knowledge in system development projects.	I am not interested in the activities of others who contribute other discipline of knowledge in system development projects.	The verb "interested" c.f. "not interested" has a non-inverse connotation.
27	I am interested in knowing how the final product or system produced by a project will be supported and maintained.	I am not interested in knowing how the final product or system produced by a project will be supported and maintained.	The verb "interested" c.f. "not interested" has a non-inverse connotation.
28	I believe that I will enjoy participating in strategic planning that decides future directions.	I believe that I will not enjoy participating in strategic planning that decides future directions.	The verb "enjoy" c.f. "not enjoy" has a non-inverse connotation.

There are two schools of thought about the reverse wording technique. One school of thought does not recommended using mixed positive and negative statements because it can reduce the reliability and validity of instruments [40]. Another school of thought recommended the use of mixed positive and negative items in a questionnaire because it can significantly reduce the 'response set'. This study shows that the questionnaire with reverse wording shows better evidence of validity. This study also provides evidence that this practice contributed to a reduction in 'response set' and that the benefit from reducing response set is greater than the 'cost' of lower reliability [40]. This result supports the finding of superiority of reverse wording with the mixed positive and negative statements in the questionnaire and test construction literature.

The results also indicate that the three-factor, 16-item construct is a better representative of both versions of the questionnaire, whether the questionnaire has only positive questions or a mix of positive and negative questions. These results support the conceptualisation of affective engagement of systems thinking construct along three dimensions: preference or inclination towards whole of systems perspectives; interest in the intended purpose or application of the whole system under consideration or development; inclination towards participation in seeking a coherent, whole, system solutions. These three dimensions suggests that the three-factor, 16-item construct can be used for further investigation of students' affective engagement development with theoretical, methodological and practical dimensions of

systems thinking during the systems engineering course or the entire extent of an systems engineering degree program.

However, because this questionnaire is newly developed, it is also recommended that researchers continue to test the psychometric properties in a bigger sample size than the sample size used in these studies. Researchers could also use a random selection technique, which was not used in this study because of the lack of participating institutions which offer systems engineering. Such research could also include test and re-test reliability, another psychometric property for the questionnaire which is not covered in this study. Further validities studies, such as examining concurrent validity, can be established through a comparison with some criterion external to the test, for example, students' performance in systems thinking.

VI. ACKNOWLEDGEMENT

REFERENCES

[1] C. M. T. Lamb, "Collaborative Systems Thinking: An exploration of the mechanisms enabling team systems thinking," Doctor of Philosophy, Department of Aeronautics and Astronautics, Massachusetts Institute of Technology, 2009.

[2] R. S. Kirby, S. Withington, A. B. Darling, and F. G. Kilgour, *Engineering in History*, Dover ed. New York: Dover Publications, 1990.

[3] E. Garrison, *A History of Engineering and Technology: Artful Methods*. Boca Raton, Florida: CRC Press, 1991.

[4] N. Kellam, J. Walther, and A. Babcock, "Complex systems: What are they and why should we care?," in *116th Annual Conference & Exposition*, Austin, Texas, 2009.

[5] M. D. Griffin, "Systems Engineering and the "two cultures" of engineering," *IEEE Engineering Management Review* vol. 3, 2007.

[6] R. Stevens, K. Jackson, P. Brook, and S. Arnold, *Systems Engineering Coping with Complexity*. Hertfordshire: Prentice Hall, 1998.

[7] A. Shafaat and C. R. Kenley, "Exploring the role of design in systems engineering," in *INCOSE International Symposium*, 2015, pp. 357-370.

[8] G. S. Parnell, P. J. Driscoll, and D. L. Henderson, "Introduction to system engineering," in *Decision Making in System Engineering and Management*, G. S. Parnell, Ed., 2nd ed New Jersey: John Wiley & Sons, 2011.

[9] Body of Knowledge and Curriculum to Advance Systems Engineering [BKCASE] Editorial Board. (2015, 28 November 2015). *The Guide to the Systems Engineering Body of Knowledge (SEBoK)*. Available: www.sebokwiki.org BKCASE is managed and maintained by the Stevens Institute of Technology Systems Engineering Research Center, the International Council on Systems Engineering, and the Institute of Electrical and Electronics Engineers Computer Society.

[10] A. F. Squires and R. J. Cloutier, "Comparing percepetions of competency knowledge development in systems engineering curriculum: A case study," presented at the 118th ASEE Annual Conference and Exposition, Vancouver, BC, Canada, 2011.

[11] A. F. Squires, "Investigating the relationship between online pedagogy and student perceived learning of systems engineering competencies," Doctor of Philosophy Dissertasion, Stevens Institute of Technology, Hoboken, NJ 07030, 2011.

[12] D. Gonçalves, "Developing systems engineers," in *Portland International Conference on Management of Engineering & Technology (PICMET)* 2008 pp. 1963-1972.

[13] Department of Defence, "Building Defence Capability: a Policy for a Smarter and More Agile Defence Industry Base," D. o. Defence, Ed., ed, 2010.

[14] A. Pyster, D. H. Olwell, T. L. J. Ferris, N. Hutchison, S. Enck, J. Anthony*, et al.* (2015, 28 November 2015). *Graduate Reference Curriculum for Systems Engineering (GRCSE®)*. Available: http://www.bkcase.org/grcse/

[15] P. Godfrey, "How systems thinking contribute to systems engineering," ed: INCOSE UK, 2010.

[16] D. Cabrera, "Systems thinking," Doctor of Philosophy Dissertation, Faculty of the Graduate School of Cornell University, Cornell University, 2006.

[17] D. Cabrera, L. Cabrera, and E. Powers, "A Unifying Theory of Systems Thinking with Psychosocial Applications," *Systems Research and Behavioral Science,* vol. 32, pp. 534-545, 2015.

[18] K. Brandstädter, U. Harms, and J. Großschedl, "Assessing system thinking through different concept-mapping practices," *International Journal of Science Education,* vol. 34, pp. 2147-2170, 2012/09/01 2012.

[19] G. Schiuma, D. Carlucci, and F. Sole, "Applying a systems thinking framework to assess knowledge assets dynamics for business performance improvement," *Expert Systems with Applications,* vol. 39, pp. 8044-8050, Jul 2012.

[20] J. Kasser, M. Frank, and Y. Y. Zhao, "Assessing the competencies of systems engineers," in *7th Bi-annual European Systems Engineering Conference (EUSEC)*, Stockholm, Sweden, 2010, p. 2010.

[21] H. L. Davidz, "Enabling systems thinking to accelerate the development of senior systems engineers," Doctor of Philosophy, Engineering Systems Division, Massachusetts Institute of Technology, 2006.

[22] O. J. H. Bosch, C. A. King, J. L. Herbohn, I. W. Russell, and C. S. Smith, "Getting the big picture in natural resource management— systems thinking as 'method' for scientists, policy makers and other stakeholders," *Systems Research and Behavioral Science,* vol. 24, pp. 217-232, 2007.

[23] R. L. Ackoff, *Creating the Corporate Future: Plan or be Planned for*. New York: Wiley, 1981.

[24] C. Churchman, *The Design of Inquiring Systems*. New York: Basic Books, 1971.

[25] P. Checkland, *Systems Thinking Systems Practice*. Great Britain: John Wiley and Sons, 1993.

[26] P. K. M'Pherson, "A perspective on systems science and systems philosophy," *Futures* vol. 6, pp. 219–239, 1974.

[27] E. Laszlo, "Systems Philosophy," in *Systems Thinking*. vol. Volume 1 General Systems Theory, Cybernetics and Complexity, G. Midgley, Ed., ed London, Thousand Oaks, New Delhi: Sge Publications, 1971.

[28] W. M. Trochim, D. A. Cabrera, B. Milstein, R. S. Gallagher, and S. J. Leischow, "Practical challenges of systems thinking and modeling in public health," *American Journal of Public Health,* vol. 96, p. 538, Mar 2006.

[29] D. Cabrera, L. Colosi, and C. Lobdell, "Systems thinking," *Evaluation and Program Planning,* vol. 31, pp. 299-310, 2008.

[30] G. Midgley, "Response to paper "Systems thinking" by D. Cabrera et al.:: The unification of systems thinking: Is there gold at the end of the rainbow?," *Evaluation and Program Planning,* vol. 31, pp. 317-321, 2008.

[31] J. Forrester, "System dynamics, systems thinking, and soft OR," *System Dynamics Review,* vol. 10, pp. 245-256, 1994.

[32] W. Ulrich, *Critical Heuristics of Social Planning: A New Approach to Practical Philosophy*. Bern: Haupt, 1983.

[33] J. T. Boardman, *Industrial Innovation, Volume 4 : Systems Thinking : Coping with 21st Century Problems*. Boca Raton, FL, USA: CRC Press, 2008.

[34] F. Camelia, T. L. J. Ferris, and D. H. Cropley, "Development and initial validation of an instrument to measure students' learning about systems thinking: The affective domain " in *Systems Journal, IEEE*, ed, 2015.

[35] G. Coricelli, R. J. Dolan, and A. Sirigu, "Brain, emotion and decision making: the paradigmatic example of regret," *Trends in Cognitive Sciences,* vol. 11, pp. 258-265, 6// 2007.

[36] A. Bechara, "The role of emotion in decision-making: Evidence from neurological patients with orbitofrontal damage," *Brain and Cognition,* vol. 55, pp. 30-40, 6// 2004.

[37] S. R. Quartz, "Reason, emotion and decision-making: risk and reward computation with feeling," *Trends in Cognitive Sciences,* vol. 13, pp. 209-215, 5// 2009.

[38] R. J. MacFadden and D. Schoech, "Neuroscience, the Unconscious and Professional Decision Making: Implications for ICT," *Journal of Technology in Human Services,* vol. 28, pp. 282-294, 2010/10/29 2010.

[39] M. D. Gall, J. P. Gall, and W. R. Borg, *Educational Research: An Introduction*, 8th ed. Boston, MA: Pearson Education, Inc., 2007.

[40] B. Johnson and L. Christensen, *Educational Research: Quantitative, Qualitative, and Mixed Approaches*, 4th ed.: SAGE Publications, Inc., 2012.

[41] R. Kumar, *Research Methodology: A Step-by-Step Guide for Beginner*, 3rd ed. London: SAGE Publications, 2011.

[42] A. P. Rovai, M. J. Wighting, J. D. Baker, and L. D. Grooms, "Development of an instrument to measure perceived cognitive, affective, and psychomotor learning in traditional and virtual classroom higher education settings," *The Internet and Higher Education,* vol. 12, pp. 7-13, 2009.

[43] M. D. Lammi, "Student achievement and affective traits in electrical engineering laboratories using traditional and computer based instrumentation," Master of Science in Engineering and Technology Education, Utah State University, Logan, Utah, 2009.

[44] Y. S. Rivera, "Promoting motivation through mode of instruction: the relationship between use of affective teaching tachniques and motivation to learn science," Doctor of Education, Lehigh University, 2010.

[45] J. W. Creswell, *Educational Research: Planning, Conducting, and Evaluating Quantitative and Qualitative Research*, 4th ed. Boston, MA: Pearson, 2012.

[46] M. Frank, "Assesing interest for systems engineering positions' required capacity for engineering systems thinking (CEST)," *Systems Engineering,* vol. 13, pp. 161-174, 2010.

[47] D. Muijs, *Doing Quantitative Research in education with SPSS*, 1st ed. London: SAGE Publications, 2004.

[48] A. B. Costello and J. W. Osborne, "Best practices in exploratory factor analysis: Four recommendations for getting the most from your analysis," *Practical Assessment, Research & Evaluation,* vol. 10, 2005.

[49] J. Hair, W. Black, B. Babin, and R. Anderson, *Multivariate Data Analysis* 7th ed. NJ, USA. : Prentice-Hall, Inc. Upper Saddle River, 2010.

[50] J. F. Hair, R. E. Anderson, R. L. Tatham, and W. C. Black, *Multivariate Data Analysis*, 4th ed. ed. New York: Prentice-Hall, 1998.

[51] D. C. Howell, "The treatment of missing data," *The Sage handbook of social science methodology,* pp. 208-224, 2007.

[52] D. George and P. Mallery, *SPSS for Windows Step by Step: a Simple Guide and Reference*, 14.0 update ed. Bacon, Boston: Pearon/Allyn, 2007.

[53] D. H. Cropley, J. C. Kaufman, and A. J. Cropley, "Measuring creativity for innovation management," *Journal of Technology Management & Innovation,* vol. 6, pp. 13-30, 2011.

[54] A. Field, *Discovering statistic using SPSS*, 3rd ed. Los Angeles, London, New Delhi, Singapore, Washington DC: SAGE, 2009.

[55] A. L. Comrey and H. B. Lee, *A First Course in Factor Analysis* 2nd ed. Hillsdale, NJ: Lawrence Erlbaum, 1992.

[56] G. Cao and Y. Duan, "A path model linking business analytics, data-driven culture, and competitive advantage," presented at the 22nd European Conference on Information Systems, Tel Aviv, 2014.

[57] L. T. Hu and P. M. Bentler, "Cutoff criteria for fit indexes in covariance structure analysis: conventional criteria versus new alternatives," *Structural Equation Modeling-a Multidisciplinary Journal,* vol. 6, pp. 1-55, 1999.

[58] M. W. Browne and R. Cudeck, "Alternative ways of assessing model fit," *Sociological Methods & Research,* vol. 21, pp. 230-258, Nov 1992.

[59] H. W. Marsh and K. T. Hau, "Assessing goodness of fit: Is patrimony always desirable?," *Journal of Experimental Education,* vol. 64, p. 364, Summer96 1996.

[60] S. Jowett and N. Ntoumanis, "The Coach-Athlete Relationship Questionnaire (CART-Q): development and initial validation," *Scand J Med Sci Sports,* vol. 14, pp. 245-57, Aug 2004.

[61] F. Li and P. Harmer, "Confirmatory Factor Analysis of the Group Environment Questionnaire with an Intercollegiate Sample," *Journal of Sport & Exercise Psychology,* vol. 18, pp. 49-63, Mar 1996.

[62] S. J. Kline, *Conceptual Foundations for Multidisciplinary Thinking*. California: Stanford University Press, 1995.

[63] P. B. Checkland and S. Holwell, *Information, Systems and Information Systems*. Chichester: Wiley, 1998.

Fanny Camelia received the degrees B.Eng, in industrial engineering, Andalas University, Indonesia, in 2003 and M.PrjMgmt, in applied project management, University of Adelaide, Adelaide, South Australia in 2011. She is currently working toward the Ph.D. degree in systems engineering at University of South Australia, Mawson Lakes, Australia.

From 2003 to 2005, she was a Research Assistant in a collaborative project between Andalas University and Padang Cement Indonesia (now Cement of Indonesia). From 2005 to 2010, she was a Lecturer with the Ekasakti University, Padang, Indonesia. Her research interests include systems thinking, systems engineering, engineering education, project management, production, logistics and inventory systems.

Timothy L.J. Ferris (M'91–SM'02) received the degrees B.E.Hons, University of Adelaide, Adelaide, South Australia in 1982, B.Th., Flinders University, Adelaide, SA in 1988, B.Litt.Hons., Deakin University, Geelong, Victoria in 1991, GradCertEd, Queensland University of Technology, Brisbane, Queensland in 2002, and PhD, University of South Australia, Adelaide, SA in 1997. All these universities are in Australia. His PhD was in the area of the theory of measurement.

He worked as an Engineer for the Electricity Trust of South Australia and Morrison Court Pty Ltd, and as a Church Worker in the Presbyterian Church of Australia before commencing as a faculty member in engineering in University of South Australia, at Mawson Lakes, South Australia, in 1991. He has published about 130 papers in journals and conferences and various other contributions to the scholarly literature. His current research interests relate to foundational issues in systems engineering, cross cultural issues in systems engineering, engineering education and research methods.

Dr Ferris is a member of INCOSE. He was Secretary of the IEEE South Australia Section (2004-2005), Publication Chair for the SoSE 2014 conference, and is an Associate Editor of *IEEE Systems Journal*.