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Work in Progress – An Engineering Economy Concept Inventory

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Abstract

It is not easy to demonstrate increases in learning of course concepts as a result of new teaching methodologies since reliable and valid tools for assessing learning are not readily available for many curriculum areas. While there are a number of accepted concept inventories available for some engineering topics including statics and dynamics, heat and energy, signals and systems as well as statistics, we are not aware of any for engineering economy. This paper will discuss work in progress on the Engineering Economy Concept Inventory (EECI) which can be used to assess learning in any introductory engineering economy course. It was originally developed in 2009 for use in assessing the effectiveness of model-eliciting activities in the classroom and has since been revised and reformulated a number of times. In the fall of 2015 the EECI was given to two large sections of an engineering economy class both at the beginning and end of the course. It was the presented at a professional conference in the summer of 2016 and revised based on an analysis of the results of the 2015 implementation as well as input from engineering economy educators. In the fall of 2016, the EECI was again given to two large sections of an engineering economy class and these results are analyzed to determine its reliability and validity for assessing learning in engineering economy. In this paper we will discuss these results and plans for further study and distribution of the inventory.

Motivation

It has become increasingly more important that we effectively assess the value of the various teaching pedagogies that have been introduced in our engineering classrooms. Many studies have been able to show clear increases in student engagement and improvements in the engineering classroom environment as a result of new and innovative teaching methods. Research has also shown that new teaching pedagogies can improve attainment of expected learning outcomes, specifically student attainment of the ABET a-k outcomes that are so important to the engineering accreditation process. Fewer studies have demonstrated a significant increase in actual learning of course concepts (which is the ultimate goal, of course!) Showing learning increases is not as easy to do since reliable and valid tools for assessing learning are not readily available for many curriculum areas. Since instructors are naturally more willing to put their efforts into evidence-based teaching practices it is critical that we are able to measure whether learning increases have occurred as a result of new practices.

Concept inventories (CIs) are available for such engineering topics as statics and dynamics, heat and energy, signals and systems as well as statistics, however there are no proven valid, reliable CIs available for engineering economy. Thus we are interested in developing such a tool. In this paper we will discuss the development of the Engineering Economy Concept Inventory (EECI), results from assessment of its validity, and plans for further study and distribution of the inventory.

Background

The Force Concept Inventory (FCI) is a multiple choice test designed to monitor students' understanding of the conceptual domain of force and related kinematics [1]. Often cited as the first concept inventory [2], it was one of the earliest and most well-known instruments in the sciences and there have been quite a few follow up studies that have looked at its validity in a variety of contexts. It is used frequently to assess concept learning in physics courses. Concept inventories are used extensively in physics and astronomy [3] [4] as well as biology [5]. Examples include the Statistical Reasoning in Biology Concept Inventory (SRBCI) [6] and the Biological Experimental Design Concept Inventory (BEDCI) [7]. Many of these concept inventories have been studied extensively for reliability and validity.

There are over 20 fairly well known instruments or concept inventories for a variety of topics specific to engineering. Some of the more well-known instruments include the Statistics Concept Inventory (SCI) which includes 38 multiple choice questions representing 4 conceptual categories [8]. Steif and Dantzler [9] introduced a Statics Concept Inventory (which is sometimes referred to as the Concept Assessment Tool for Statics or CATS). It has 27 multiple choice questions representing 9 concepts. The Dynamics Concept Inventory (DCI) [10] includes 29 multiple choice questions representing 14 categories taken directly from the FCI. Interestingly, the developers of the Signals and Systems Concept Inventory (SSCI) cited a similar motivation as discussed here for the EECI… "The signal processing community needs quantitative standardized tools to assess student learning in order to improve teaching methods and satisfy accreditation requirements" [11]. It is a 25 item multiple choice exam. Identifying misconceptions is cited as one of the uses of the Heat and Energy Concept Inventory (HECI) which has 36 multiple choice questions with 4 subscales (or categories) [12]. A literature search has not led to discovery of any studies showing work on a concept inventory for engineering economy.

History of the Engineering Economy Concept Inventory

The EECI was originally developed in 2009 for use in assessing the effectiveness of model-eliciting activities (MEAs) in the classroom [13]. This original 9 item (mix of multiple choice and short answers) concept inventory was given to two sections of an engineering economy course both at the start of the semester and at the end of the semester. Both sections of the course were taught by the same instructor using the same course materials but one of the sections utilized the MEAs and the other did not. While an increase in the score on the concept inventory would naturally be expected from pre to post semester in any course regardless of teaching pedagogies, in this study we found the effect size to be significantly larger in the section of the course taught using MEAs. Thus we were able to use the EECI to demonstrate the effectiveness of using MEAs.

In 2012, the EECI was again used to study whether learning increases could be seen with the use of a particular teaching methodology. This time, the teaching method of interest was a student response system or "clickers" [14]. Again, two sections of the course, taught by the same instructor, using the same course materials were given the concept inventory both at the beginning and end of the semester. One section of the course was taught using the student response system and the other was not. Once again, as expected, there was an increase in the average score on the concept inventory for both sections of the course. While the effect size was larger for the section taught using the clickers, it was not enough to conclude that learning of course concepts was improved due to the use of the clickers. We were able to conclude, however, that learning of course concepts was not negatively affected by the use of clickers and the study did conclude that students were more engaged in the classroom (creating an improved classroom environment) as a result of the use of the student response system.

There was a surprising amount of interest in the concept inventory following the presentation of these studies and a good bit of discussion of the inventory with engineering economy educators. There was also some criticism (justified) about the validity of the EECI as a tool to measure learning and some doubt as to whether it could legitimately be referred to as a "concept inventory". The term "concept inventory" has come to mean a specific type of test. The American Society for Microbiology, for example, defines a concept inventory as a tool "designed to help faculty evaluate students' understanding of a specific set of concepts and identify misconceptions [15]." And in Physics, CIs have been defined as "research-based assessment instruments that probe students' understanding of particular physics concepts" [3]. The EECI had not yet been put to any extensive tests for reliability and validity.

This led the author of the EECI to investigate the use of concept inventories in other areas as well as to find and apply methods that are used to validate such tools. The author is certainly not the first to do so. In fact, the Division of Undergraduate Education of the National Science Foundation sponsored a workshop ("*Assessing the State of STEM Concept Inventories: A National Workshop*" DUE-0731232) and a subsequent panel session was held at the 2007 Frontiers in Education Conference (jointly sponsored by ASEE and IEEE) to discuss CIs as a tool to facilitate better teaching and learning [16].

Steif and Hansen [17] (developers of the Statics Concept Inventory, which they refer to as the SCI but others have referred to as the CATS – presumably so as not to be confused with the well-known Statistics Concept Inventory) argue that the potential value of concept inventories can be significantly enhanced if they are given online and if scores are compared with other measures of performance. They showed that the Statics Concept Inventory is strongly positively correlated with class exams. They also argued that one can analyze wrong answers to detect patterns indicating a consistent misconception. Two of the actions taken on the EECI (which are describe later in this paper) were to move it online and to compare scores with other measures of performance in the class.

Ogunfunmi, Herman, and Rahman [18] did a study of the use of CIs in circuits and systems courses. They recognized that CIs offer the engineering education community reliable and accepted means to assess and compare different teaching methods. They also proposed a number of ways to improve their use in that field including expanding coverage of topics and getting the circuits and systems educational community involved. The EECI has been expanded to include more topics and we are currently in the process of engaging the engineering economy community in improving its effectiveness.

Jorion, et. al. [19] have presented a framework for testing the validity of concept inventory claims. They categorized the types of claims that are typically made by concept inventories and then set out to find support for each type of claim for the SCI (Statistics Concept Inventory), CATS (Concept Assessment Tool for Statics), and DCI (Dynamics Concept Inventory) using the framework they proposed. The types of claims they outlined for concept inventories are those that enable one to infer 1) students' overall understanding of all concepts identified in the CI, 2) students' understanding of specific concepts, and 3) students' propensity for misconceptions or common errors. The authors found varying degrees of support for the claims. They found support for 1) with the CATS and DCI, and support for 2) with CATS, but no support for 3) for any of the inventories.

Since the EECI was first used in 2009 it has been revised and reformulated a number of times. At this point in the development of the EECI it is only expected to be able to infer students' overall understanding of engineering economy concepts and possibly students' understanding of specific engineering economy concepts but no effort has been made to determine if it can find students' propensity for misconception or common errors. We are currently in the process of applying the framework proposed by Jorion, et. al. [19] to assess the reliability and validity of the EECI.

Methodology

In the fall of 2015, the EECI was revised and administered via Blackboard (on line) and included 11 questions, 7 of which were multiple choice and 4 were essay/short-answer. The questions were worth 5 points each for a total of 55 points possible. The multiple choice questions were automatically score (0 or 5, wrong or right) while the essay questions were scored by hand on a 0-5 point scale based on specific rubrics. It was given to two large sections of an engineering economy class both at the beginning and end of the course. One section of the course was taken primarily by industrial engineering (IE) students, while the other was a mix of students from a variety of other engineering disciplines. Since the goal of this implementation was to study the EECI itself and not to use it to measure the impact of any particular teaching method, the courses were taught in exactly the same manner.

Paired t-tests were done to compare the pre and post course scores on the EECI for 56 students in the IE section and 54 students in the non IE section. While there was a significant increase in the total score for both sections of the course, in the IE section no significant increase in score was found for 4 of the 11 questions and in the non IE section no significant increase in score was found for 3 of the 11 questions. A total of 6 unique questions proved to be problematic in demonstrating learning increases and in fact, scores decreased on 2 of those problematic questions. In addition, only a weak correlation was found between students' post EECI scores and their final course grade as well as final exam scores for both sections of the course.

The EECI and these preliminary results were presented at the Institute of Industrial and Systems Engineer's Annual conference in May 2016 and input from engineering educators was sought on how best to revise the problematic questions. As a result of this discussion as well as research into effective concept inventories, the EECI was revised over the remaining summer. All problematic questions were either removed or reworded for clarification. All questions were changed to multiple choice or numeric answer to eliminate any grading bias. Additional questions were added and questions were categorized into 5 broad concept areas.

The inventory now consists of 17 multiple choice and 3 numeric response questions categorized as follows:

- Costing and Basic Concepts - 5 questions
- Time Value of Money - 6 questions
- Time Value of Money Decision Making – 4 questions
- Benefit-Cost Ratios – 2 questions
- Miscellaneous Concepts – 3 questions

All of the questions are automatically scored in Blackboard with each question being worth 5 points for a total possible score of 100. Figure 1 provides a screen shot of a sampling of the questions. In order to manage copyright privileges, we are not providing the full inventory in this paper, however it will be shared during the presentation of this paper and can be obtained upon special request.

The EECI was again given to two large sections of the engineering economy class in the fall of 2016 both prior to the start of the term and again at the end of the term. One section of the course again consisted primarily of industrial engineering students (63 students enrolled) while the other consisted of a mix of engineering disciplines (71 students enrolled). We will refer to these as the IE and the non IE section respectively. At the beginning of the course students were told that the concept inventory was a required part of the course but that scores would not affect their overall course grade. To incentivize students to do their best on the post course EECI but to also avoid the pressure of needing to score well in order to benefit their course grade, students were told that if they scored at least a 75 on the EECI that they would earn 50 bonus points towards their homework grades. Due to an issue with one of the questions (to be discussed later in this paper), this was later revised to a score of at least 70.

Results

To effectively compare the pre and post scores and begin to assess the reliability and validity of the EECI only those students that completed the entire concept inventory both pre and post course were included in the data set. This resulted in a sample size of 52 for the IE section and 64 for the non IE section.

QUESTION 16 5 points Save Answer

As the interest rate increases, the net present value of an investment will:

- a. Increase
- b. Decrease
- c. Not enough information is provided to determine this

QUESTION 13 5 points Save Answer

If I deposit $3,540 in an account earning 8% per year, how much money will accumulate in 7 years? Provide your answer to 2 decimal places.

QUESTION 8 5 points Save Answer

Two machines are being considered for the production of a part. Material costs are $6 per part. Labor costs are $20 per hour. The selling price is $12.00 per part. The first machine (Machine A) can produce 100 parts per hour and is available for 7 hours per day. 3% of the parts produced on Machine A are expected to be rejected (production costs still apply to rejected parts but they cannot be sold!). Machine B can produce 130 parts per hour and is available 6 hours per day. 10% of the parts produced by Machine B are expected to be rejected. Assuming that all parts that are not rejected are sold, which machine should be selected based on expected daily profit?

- a. Machine A.
- b. Machine B.
- c. Both machines are equivalent.
- d. There is not enough information provided to determine.

QUESTION 4 5 points Save Answer

Given that a product is sold in a competitive market and the product is not a basic necessity, its price and demand are likely:

- a. Independent
- b. Dependent
- c. It depends on how many competitors there are.
- d. There is not enough information provided to determine this.

Figure 1: Samples of EECI questions as they appear in Blackboard

Average scores for the pre and posttest for both sections of the course are shown in Table 1. For both sections of the course total scores and scores on every question were improved pre to post… certainly an expected outcome. The Cohen's d gain was 3.42 for the IE section and 3.69 for the non IE section (both considered very large). The differences (using paired t-tests) were significant for all but 4 questions in the IE section and all but 3 question in the non IE section (5 unique questions). It is hypothesized that the reason that the differences were not significant for questions 3-6 was because many students took the EECI after the first day of lecture and some of those questions were likely answered during that lecture which gave them high scores on both the pre and post EECI. This issue that was overlooked by the instructor and, of course, best practices suggest giving the pre-test prior to any coverage of course material. Again, scores were higher on the post test for all questions and a one tailed test would be significant for question 6 in both sections.

	Non IE Section (n=64)		Two-Tailed	**IE Section (n=52)**		Two-Tailed
	Pre Mean	Post Mean	p value	Pre Mean	Post Mean	p value
Total	49.10	85.55	0.00	48.65	83.65	0.00
Question						
1	1.25	3.44	0.00	1.44	3.27	0.00
2	2.42	5.00	0.00	3.17	4.81	0.00
3	4.53	4.77	0.26*	4.52	4.62	0.66*
4	3.83	4.69	0.00	4.13	4.62	0.17*
5	4.38	5.00	0.00	4.52	4.81	0.08*
6	4.53	4.92	0.06*	4.42	5.00	0.01
7	1.25	4.84	0.00	1.35	4.90	0.00
8	2.89	3.75	0.03	2.40	3.46	0.02
9	1.02	4.14	0.00	0.77	4.04	0.00
10	1.33	4.06	0.00	1.35	4.23	0.00
11	4.53	5.00	0.01	4.04	4.90	0.00
12	4.22	4.84	0.02	4.13	5.00	0.00
13	2.89	4.53	0.00	2.79	4.04	0.01
14	0.08	4.61	0.00	0.19	4.42	0.00
15	0.00	1.64	0.00	0.00	1.92	0.00
16	2.34	4.77	0.00	1.25	4.71	0.00
17	1.64	4.69	0.00	1.54	4.62	0.00
18	1.88	4.77	0.00	2.11	4.71	0.00
19	4.06	4.45	0.20*	4.52	4.42	0.71*
20	0.00	1.64	0.00	0.00	1.15	0.00

*Indicates not significant (α=.05)

Table1: Paired t-test for differences between pre and post EECI scores

The reason that the difference was not significant for question 19 is more difficult to explain and could demonstrate a problematic question that requires further revision. This question reads:

Question 19

Fill in the blanks for this statement:
If the net present value of all of the cash flows associated with an investment opportunity is a positive value at a company's "required" rate of return, then the internal rate of return for that investment is ______ than the company's required rate and the investment is a ______ investment for this company.

a. Lower, Good
b. Lower, Bad
c. Higher, Good
d. Higher, Bad

As will be discussed next, this question did not fall out of acceptable ranges of item difficulty or item discrimination. From an anecdotal perspective although it doesn’t seem like something that most students would know prior to taking the course, many of the IE students got it correct on the pre-test and were perhaps overthinking it on the post-test. In any case, the lack of a significant difference pre to post is hard to explain.

Next the post scores on the inventory were correlated with both final exam scores and overall course averages. These results are shown in Table 2. Correlations for the Statics Concept Inventory score and exam scores ranged from .387 to .614 [17]. So only the IE section results are showing potential for good correlations for the EECI.

Non IE Section (n=68)		IE Section (n=57)	
Post Test Score vs. Course Grade	Post Test Score vs. Final Exam Score	Post Test Score vs. Course Grade	Post Test Score vs. Final Exam Score
0.21	0.13	0.43	0.30

Table 2: Pearson correlation coefficients for EECI results

Finally, two problematic questions emerged and an explanation is required for the very low average scores for these on the posttest. These were Question 15 and Question 20, both of which were calculated response questions where students were required to enter a numeric response. Question 15 had an error in the problem statement where the planning horizon or project life was given as a variable but then listed as a specific number later in the problem statement. Thus students were naturally confused about what year to use to compute the present equivalent of the salvage value. This error will of course be corrected when the EECI is administered again. Question 20 asked for the equivalent uniform annual cost (EUAC) but it was unclear whether a positive or negative value should be entered. The correct response was only set up to accept positive values. This will also be corrected in the next version of the inventory.

Reliability and Validity Discussion

In order to perform some of the reliability and validity tests, the IE and non IE data sets were combined and all students that completed the posttest were included. This gave us a sample size of 125 for these tests.

First, item difficulties or percentage of students who answered each question correctly were computed. Per the Jorion, et. al. [19] framework for CIs, the most effective items overall have mid-ranges of difficulty and a CI would be considered excellent for item difficulty if the questions have scores ranging between .2 and .8. The item difficulties are shown in Table 3. Unfortunately quite a few (11 questions) have values above .9. Clearly some work needs to be done to make some of the EECI questions a bit more challenging.

Next we computed the item discriminations or the correlation between each question score and the total score. These are shown in Table 4. Here (again per Jorion [19]) we are looking for positive correlations above .2 so there are only four questions that are not well correlated with the total score on the EECI.

One way to measure overall concept inventory reliability is to use Cronbach's alpha which will give us an indication of whether a given student's total score would be nearly the same if we were to give the test multiple times to the same student. Cronbach's alpha when all 20 questions are included is .617 and when the four questions with poor discrimination (Questions 6, 12, 13, and 16) are removed the Cronbach's alpha improves to .667. Greater than .65 is considered "average" thus giving us an indication that while certainly not where it needs to be, the EECI has potential for success as a concept inventory.

Question	% of students correct	Question	% of students correct
Q1	0.672	Q11	0.992
Q2	0.968	Q12	0.976
Q3	0.944	Q13	0.856
Q4	0.912	Q14	0.888
Q5	0.976	Q15	0.336
Q6	0.992	Q16	0.944
Q7	0.944	Q17	0.928
Q8	0.728	Q18	0.952
Q9	0.816	Q19	0.880
Q10	0.832	Q20	0.264

Table 3: Item Difficulties (% of students with correct response)

Question	Correlation with total score	Question	Correlation with total score
Q1	0.603	Q11	0.285
Q2	0.238	Q12	0.083
Q3	0.334	Q13	0.132
Q4	0.419	Q14	0.523
Q5	0.278	Q15	0.430
Q6	0.075	Q16	0.010
Q7	0.448	Q17	0.321
Q8	0.463	Q18	0.206
Q9	0.486	Q19	0.425
Q10	0.417	Q20	0.454

Table 4: Item Discrimination (correlation with total score)

Future Work

There are, of course, additional models that can be applied (item response theory, exploratory factor analysis) to test for reliability and validity of the EECI, however at this point we believe further revision is necessary before performing any of these tests. We intend to first correct the two problematic questions. One solution may be to revise all three of the numeric response questions and replace them with multiple choice questions. The reason for doing this would be so that the EECI is better able to identify misconceptions. The multiple choices can be structured so that the options include answers which would be found if a student makes a particular error. So a high number of incorrect responses with the same wrong choice would indicate students' overall misconceptions on a particular problem.

Some of the questions with difficulty scores above .9 will be revised as well. In addition to increasing the difficulty, the goal is to identify misconceptions by providing incorrect options appropriately.

Finally, because the order of the questions remained the same for all students on both the pre and post test, it is possible there could have been some "guessing" on the post test since students were told they only needed a score of 75 to pass. Thus if a student were confident about the first three fourths of his or her answers, then they may have chosen to simple guess on the latter questions. Therefore for future tests, we should take advantage of the ability to randomize the order of the questions in the Blackboard test environment.

Next the concept inventory will again be given to two sections of engineering economy in the fall of 2017 (ensuring that all students take the pretest prior to the first lecture.) Finally, the author will seek collaborators from other universities who can administer the concept inventory post course in order that we may increase the sample size for the reliability testing.

Based on results so far, it has been shown that the EECI has tremendous potential to become an effective tool for assessing learning in engineering economy. It can therefore be a valuable asset for use in educational research studies that attempt to show the effectiveness of a particular teaching methodology or to verify student outcomes as related to accreditation.

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