**An Engineering Economy Concept Inventory**

Karen M. Bursic

*University of Pittsburgh*

kbursic@pitt.edu

<http://orcid.org/0000-0003-1438-9072>

Karen M. Bursic, Ph.D., P.E, is an Associate Professor and the Undergraduate Program Director in Industrial Engineering at the University of Pittsburgh. She received her B.S., M.S., and Ph.D. degrees in Industrial Engineering from the University of Pittsburgh. Prior to joining the department she worked as a Senior Consultant for Ernst and Young and as an Industrial Engineer for General Motors Corporation. She teaches courses in engineering economics and engineering management in Industrial Engineering as well as engineering analysis and computing in the First Year Engineering program. Dr. Bursic’s recent research has focused on improving Engineering Education and she has 25 years of experience in this area. She has also done research and published work in the areas of Engineering and Project Management. Dr. Bursic is a senior member of the Institute of Industrial Engineers and the American Society for Engineering Education and a registered Professional Engineer in the state of Pennsylvania.

# Abstract

There has been considerable recent emphasis on valid assessment of learning in engineering education. When new teaching pedagogies are introduced, it can be very challenging to demonstrate increases in learning of course concepts. While there are a number of accepted concept inventories available for some engineering topics (statics and dynamics, heat and energy, signals and systems, and statistics), reliable and valid tools for assessing learning are not readily available for many curriculum areas, including engineering economy. This paper discusses the reliability and validity of the Engineering Economy Concept Inventory (EECI) that can be used to assess learning in any introductory engineering economy course. Development of the EECI began 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 2018, the EECI was administered at multiple institutions for further evaluation of its validity and results from these groups of students are presented. The paper concludes with remarks regarding the reliability and validity of the instrument and recommendations for its use as a tool to assess knowledge in engineering economy.

Keywords: engineering economy, education, concept inventory, assessment

# Motivation

With the introduction of new teaching pedagogies such as active learning, problem-based learning, classroom “flipping”, student response systems, hybrid and online courses, and others comes the need to assess the effectiveness of such methods. It is one thing to demonstrate that new teaching methods can increase student engagement in the classroom, improve the overall classroom environment, or even improve students’ attainment of the ABET[[1]](#footnote-1) required student outcomes. However, it is an entirely different matter to demonstrate that these interventions actually increase student learning of core concept knowledge. The former has been done and the education literature is full of examples. To effectively do the latter, one must have valid, reliable assessment tools. If an instructor uses their own exams and other course assessments, it can introduce a bias that can cause the results to be called into question. Targeted, independent assessment tools are not readily available for many curriculum areas including engineering economic analysis, a required curriculum area for industrial engineers and often for other engineering disciplines. The introduction of new teaching pedagogies is time consuming and challenging. If engineering schools expect faculty to put their efforts into new and innovative methods that they hope will spark the interest of today’s students, then it is important to be able to provide evidence that these teaching practices, at minimum, do not negatively affect the learning process and, preferably, increase learning of core course concepts. Finally, in an editorial in the *Journal of Engineering Education* (Douglas and Purzer 2015), the authors point to numerous engineering education researchers who have called for an increase in the rigor of research in engineering education and the associated need for high-quality assessment tools.

One such assessment tool that has been proven worthwhile in a variety of engineering curricula areas is the Concept Inventory (CI). Reliable, valid CIs are available for statics and dynamics, heat and energy, signals and systems as well as statistics. To our knowledge, however, there are no proven valid and reliable CIs available for engineering economy. This paper presents the development of one such CI, known as the Engineering Economy Concept Inventory (EECI). Work on the EECI was originally published and presented as a work in progress at the American Society for Engineering Education’s (ASEE) annual conference (Bursic 2017) with reliability and validity results from a specific study done at one institution in 2016. Given the response to this work (including a “Best Paper” award), the researcher has continued to develop the EECI. The current paper is the result of further refinement of the EECI and additional data collected from multiple institutions in the fall of 2018.

# Literature Review

Often cited as the first concept inventory (Hestenes, et. al. 1992), the Force Concept Inventory (FCI) is a multiple-choice test designed to monitor students’ understanding of the conceptual domain of force and related kinematics (Savinainen and Viiri 2008). The vast majority of CIs use multiple-choice questions aimed not only at determining student understandings of concepts but also at identifying student misconceptions with respect to concepts. The FCI is one of the earliest and most well-known instruments in the sciences and is used frequently to assess concept learning in physics courses. It has been studied for its reliability and validity in a number of contexts and it continues to be frequently cited. The fields of physics, astronomy, and chemistry often use concept inventories to assess learning (Madsen, et. al. 2016; Wallace and Bailey 2010; Dick-Perez, et. al. 2016). The Statistical Reasoning in Biology Concept Inventory (SRBCI) and the Biological Experimental Design Concept Inventory (BEDCI) are examples of concept inventories used in Biology (Smith and Tanner 2010; Deane, et. al. 2016; Deane et. al. 2014). CIs are used in other life science as well. McFarland, et. al. (2017) recently presented a Homeostasis Concept Inventory (HCI) which they showed to be effective in assessing concept understanding in that area of study. The literature also reveals their use in health sciences (Seitz, et. al. 2017; Stevens, et. al. 2017). While mathematics educators are also using CIs, in a study done by Gleason, et. al. (2018) the authors concluded that one commonly used calculus concept inventory lacks sufficiently strong validity and reliability. The conclusion was based on data from 1800 students across four institutions and the authors determined that there is a need for a new instrument to better measure conceptual understanding of calculus concepts. It suffices to conclude that the concept inventory has become quite a popular assessment tool in many fields of study but not all fields have developed strong instruments. Much research is ongoing and a quick literature search using the keywords “concept inventory” bears this out.

Specific to the general field of engineering, there are numerous well-known CIs for a variety of common engineering topics. A few examples are discussed here. Stone, et. al. (2003) developed the Statistics Concept Inventory (SCI), which has seen frequent use specifically in engineering. (Other statistics concept inventories have been used in different fields.) This CI has 38 multiple-choice questions representing four conceptual categories. It has been used to assess student knowledge in probability and statistics and demonstrate attainment of ABET outcomes. The Statics Concept Inventory (which is sometimes referred to as the Concept Assessment Tool for Statics or CATS) was first introduced by Steif and Dantzler (2005). It has 27 multiple choice questions representing 9 concepts. In a recent study that used this inventory, Brown, et. al. (2019) compared student results to those of working professionals. Although their results showed that students outperformed the working professionals, they cautioned against drawing conclusions that students necessarily have a better understanding of concepts than do working professionals. Instead they indicate that their “results suggest that differences in the way concepts are situated and applied across school and workplace contexts might account for the differences in the performance observed.” The Signals and Systems Concept Inventory (SSCI) is a 25 item multiple-choice exam. Its developers indicate that “The signal processing community needs quantitative standardized tools to assess student learning in order to improve teaching methods and satisfy accreditation requirements” (Wage, et. al. 2005). This is a commonly cited reason for development of these tools. Other purposes include identifying students’ misconceptions, which is recognized as one of the uses of the Heat and Energy Concept Inventory (HECI). The HECI has 36 multiple choice questions with 4 subscales or categories (Prince, et. al. 2012). Some developers of CIs build their instruments from previously validated CIs. The Dynamics Concept Inventory (DCI) includes 29 multiple choice questions representing 14 categories taken directly from the FCI (Gray, et. al. 2005). Another recent study (Flynn, et. al. 2018) reported on the development of a 20-item Rate and Accumulation Concept Inventory (RACI), which is used to assess principles important to a variety of engineering disciplines. The authors concluded that based on their pilot studies of this CI, it has sufficient reliability and validity; however they indicate a need for additional research to improve it as a diagnostic tool. Thus, like many others, development of this CI is ongoing. As in many of the science fields, engineering education researchers continue to develop and study the use of concept inventories as an effective assessment tool. The research does show that with purposeful and thoughtful development, CIs can be reliable and valid tools for assessing student understanding of course concepts. The literature search has not revealed any ongoing work on a concept inventory for engineering economy.

# History of the Engineering Economy Concept Inventory

As noted earlier, when faculty introduce new teaching pedagogies in the classroom, it is often critical that we measure the effectiveness of those pedagogies. In 2009, during a study of the use of model-eliciting activities (MEAs) in the classroom, the researchers found a need to assess engineering economic analysis concept learning (Bursic, et. al 2010). The original 9 item assessment used in this study was a mix of multiple choice and short answer style questions. It was used to compare two sections of an engineering economy course, one where MEAs were being used and the other a control section taught by the same instructor. The test allowed the researchers to demonstrate a larger effect size on increased knowledge of course concepts pre to post course in the section in which MEAs were incorporated. Later, this same test was used to determine if the use of student response system or “clickers” improved course concept learning (Bursic, 2012). While no increases in learning of course concepts were noted, the assessment tool did allow the researcher to conclude that no negative effects on learning were observed and that student engagement in the classroom was increased. These results are often critical to faculty implementing new teaching pedagogies.

While there was a surprising amount of interest in the assessment tool following the presentation of these studies at some educational conferences, there was a good bit of doubt as to whether the test could be legitimately referred to as a concept inventory, since its reliability and validity were never tested. In addition, since CIs generally consist of only multiple-choice items aimed at identifying concept understanding and misconceptions, it was recognized that the test needed to be modified if it were to be recognized as such. One definition states that a CI is a “multiple-choice research-level instrument designed to test students’ conceptual understanding” (Sands, et. al. 2018). Physics researchers define CIs as “research-based assessment instruments that probe students’ understanding of particular physics concepts” (Madsen, et. al. 2016). A third definition is, “a multiple-choice instrument designed to evaluate whether a person has an accurate and working knowledge of a concept or concepts” (Lindell, et. al. 2007). Thus an effort was begun to modify the test and create a true concept inventory for the field and it is now referred to as the Engineering Economy Concept Inventory (EECI).

The Division of Undergraduate Education of the National Science Foundation sponsored a workshop entitled “*Assessing the State of STEM Concept Inventories: A National Workshop*” (DUE-0731232) as well as a subsequent panel session 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 (Reed-Rhoads, et. al. 2007). These efforts helped to spark additional research into developing effective assessment tools and recommendations for improving them. The developers of the Statics Concept Inventory also provided some direction (Steif and Hansen, 2007). They indicated 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 also showed that the Statics Concept Inventory is strongly positively correlated with class exams.

Thus, some early efforts on improving the EECI included migrating it online and evaluating correlations between it and other measures of performance in a course. Additional research on improving CIs revealed that one way to improve them is to expand coverage of topics while having the particular field’s education community involved (Ogunfunmi, et. al. 2014). Thus, the EECI and some preliminary results from a study in the fall of 2015 were presented at the Institute of Industrial and Systems Engineers’ Annual Conference in May 2016. The research on concept inventory effectiveness as well as the 2015 preliminary study revealed a number of concerns. While the overall average score on the EECI improved pre to post course, not all of the average scores on individual questions improved. In addition, the tool still contained open-ended questions. Finally, most concept inventories are structured to focus on specific categories of concepts. After this presentation, further input from engineering educators was sought on how best to revise the instrument.

Following the 2015 results, the EECI was expanded to include more topics with additional questions added. All of the problematic questions from the earlier version were either removed or reworded for clarification. All questions were changed to either multiple-choice or numeric answer to eliminate any grading bias. Additional questions were added and questions were categorized into 5 broad concept areas including Costing and Basic Concepts, Time Value of Money, Time Value of Money Decision Making, Benefit-Cost Ratios, and Miscellaneous Concepts. Then in fall 2016, the EECI was revised and administered via Blackboard (online) to two large sections of an engineering economy course at one institution both pre and post course. These results were analysed using some of the recommendations from a framework for testing the validity of concept inventory claims presented by Jorion et. al. (2015). This framework suggests using classical test theory (item difficulties, item discriminations, Cronbach’s alpha, and alpha-with-item-deleted), Item Response Theory (IRT), and structural analysis (including exploratory factor analysis). Only some of the classical test theories were applied at this point.

The results of the 2016 study revealed large gains from pre to post course on the EECI scores (measured by Cohen’s D), a consistent result from all studies of the EECI thus far. In addition, the average score on all of the 20 individual questions were higher post course than pre. However, the correlation between the post EECI scores and students’ final exam scores as well as correlation between post EECI scores and students’ final overall scores in the class remained low. The study also revealed a number of problematic questions with unclear wording. Item difficulties or percentage of students who answered each question correctly were computed for all 20 questions. Per the Jorion, et. al. framework, a CI would be considered excellent for item difficulty if the questions have scores ranging between .2 and .8. That is, questions with item difficulty scores less than .2 are considered too difficult and questions with scores above .8 are considered too easy. Unfortunately, far too many of the questions on this version of the EECI resulted in item difficulties above .9. When item discriminations were computed (the correlation between each question score and the total score), all but four questions had values above the .2 recommended by the Jorion framework.

A recommended measure of the overall reliability of a CI is Cronbach’s alpha which gives an indication of whether a given student’s total score would be nearly the same if the test were given multiple times to the same student. Cronbach’s alpha when all 20 questions of the 2016 version were included was .617 and when the four questions with poor discrimination are removed the Cronbach’s alpha improved to .667. This value is considered only “average”. The conclusion from the 2016 study was that the EECI had potential to become an effective tool for learning in engineering economy but needed further refinement as well as testing outside of the original institution’s own students if it were to be accepted as a reliable, valid CI.

Following the 2016 study and 2017 ASEE presentation the CI was once again revised. All 20 questions were reformulated as multiple-choice questions and the issue of question difficulty was addressed in a number of the items. The problematic questions were all re-worded and clarified and consideration was given to how one might identify misconceptions with particular incorrect answers. The EECI was officially published and distributed to approximately 10 faculty members of the engineering economic analysis education community. The current version of the full EECI appears in the Appendix. Correct answers will be supplied upon request from any engineering economic analysis instructor who would like to use the instrument.

# Methodology and Results

In the fall of 2018, the EECI was given at three universities to students in introductory engineering economy courses. At the University of Pittsburgh, it was given both pre and post course to two sections of the course with enrolments of 82 and 83 students. A total of 151 students took the post EECI (which is the data to be used in the various reliability and validity tests) while 145 of these students took both the pre and post EECI. This course is delivered in a traditional lecture format with considerable active learning as well as the use of a student response system. Data was also provided from 171 students at the Missouri University of Science and Technology who took the test both pre and post course. This course was a fully online course. The instructor of the Missouri course acknowledges that the students had little incentive for completing the EECI and expected that this might affect the resulting scores for some students. Data from 57 students in a traditional lecture style course at the University of Arkansas was also obtained. The data to be used in the reliability and validity discussion was from the post course EECI for all three institutions and consisted of a total sample size of 379 students. All students had just completed or were in the final weeks of their course when they took the post test. While the majority of the students in all of these courses were industrial engineering students, there were students from a variety of engineering disciplines enrolled in each. The data were not parsed by engineering discipline.

At all three Universities, students were incentivized to take the CI. At Pittsburgh, students were told:

*The post course Engineering Economy Concept Inventory (EECI) is now available on Blackboard, under “Assignments”.  You have until 5 PM on Friday December 15 to complete this test.  Remember this is part of my research in Engineering Education and is not required, participation is voluntary.  All students scoring above a 75% (at least 15 out of 20 questions correct) will earn 50 bonus points towards their Assignment grade (homework/in-class/case studies).   You may use whatever resources you like and although the test is not timed, please complete it in one attempt and one sitting.  It should not take more than about 1 hour to complete.  Be sure to hit “Save and Submit” when finished.*

At Arkansas students were told:

*A friend and colleague at the University of Pittsburgh wants to see how you all do on a "concept quiz" she developed for our course topic. This online quiz will be available to you from noon today, until midnight on Thursday, December 13. It is worth 10 bonus points towards your HW/Quiz grade if you score at least 70%. You have an hour to complete it and it must be completed in one sitting. Use any resources you like, except other people. You will be helping her research in this area, and getting a little bump in your grade.*

Students were also incentivized at Missouri; however, because students knew exactly where they stood in the class when the EECI was given the instructor indicated they had little incentive to take and do well, most not needing the bonus points. Average scores on the post EECI (one point for each of the 20 questions, 20 possible points) are shown in Table 1. The possible effect on the EECI score of familiarity to question style and/or the instructor specifically addressing known questions for the Pittsburgh students’ performance cannot be discounted. There are, of course, numerous other possible factors playing a role in the differences in these average scores. However, the author contends that in combining the data from all three institutions a reliable set of data is obtained for which to test the overall EECI validity.

INSERT TABLE 1 HERE

Table 1 Average scores on the Post EECI

As a basic first step and as had been done in the previous studies, a comparison was made of average score pre and post for the 145 common students at the University of Pittsburgh. The average pre course score was 9.15 (s=2.26) and the average post course score 18.24 (s=1.84) and a two sample t test results in a p-value=0; a clear statistical difference as expected.

Next, some classical test theory validity tests were done, beginning with question difficulties or percentage of students giving the correct response for each question. Table 2 shows the question difficulties based on responses from the combined 379 students. There remain 7 questions with difficulty scores above the mid-range recommended by the Jorion framework. This is much fewer than the 16 questions in the 2015 version and, unlike that version, there are now no questions with scores above .9, giving evidence of an improvement here.

INSERT TABLE 2 HERE

Table 2 Question difficulties for the EECI

Table 3 shows the question discriminations or correlations between item scores and total score. Items are most effective when they discriminate well between students with high and low total EECI scores. All 20 questions had discriminations above the recommended .2 value. There were four questions on the 2015 version that did not discriminate well; thus, an improvement is also seen here.

INSERT TABLE 3 HERE

Table 3 Question discriminations for the EECI

The Cronbach’s alpha for the test is .86 which is considered good (above .9 would be excellent). This is a significant improvement over the 2015 version of the EECI (.67). New tests that were done for this version included the alpha-with-item-deleted scores. Per the Jorion et. al. (2015) framework these values should be less than the overall alpha. If a question on the EECI causes an alpha-with-item-deleted score greater than or equal to the overall Cronbach’s alpha this could indicate that it is measuring a construct different from the other items. None of the EECI questions had alpha-with-item-deleted scores above the .86 (all were between .83 and .85).

While item response theory and structural analysis were beyond the scope of the current study, the author did attempt a basic regression model to determine whether a student’s expected proficiency (based on all of the other graded assessments in the course) correlated well with the EECI post score. This was performed with the n=145 students that took both the pre and post-test at Pittsburgh since this data was readily available. The model only gave an r2 value of .305 but, when unusual observations (identified by Minitab but verified by instructor knowledge of the particular students) were removed, the r2 improved to .362. Interestingly, most of the homework assignment and in class exercise scores appear to have a better correlation with the EECI score than did either the midterm, final, or quiz scores. In addition, the overall grade in the course is not well correlated with the post EECI score.

# Discussion

Overall the current version of the EECI satisfies the tests for validity to a greater extent than did the 2015 version. The 7 questions that might be considered too easy (per the difficulties measure) are not a surprise. For example, question 5 asks “Which of the following criteria can be considered in economic decision making?” In retrospect, it is fairly obvious that the “all of these” response is the correct response given how many options are presented. This question can be restructured to get at the same concept (that criteria other than simply “maximize profits” and “minimize costs” are critical in real world economic decision making.) The same can be said for question 11 which asks about factors that are appropriate to consider in determining whether to install highway lighting. Question 19, which looks at the relationship between net present value at a company’s minimum attractive rate of return and the internal rate of return, had a very high percentage of students getting it correct in the 2015 study which was left unexplained at that time. That question was consequently left unedited in this version and it continues to be too easy. This one will need to be reworded as well, along with questions 3, 6, 12, and 13.

Another issue that arose in this study was a problem with administering the test online. There are far too many ways that students today can “cheat” and it was discovered that the online solution provider, Chegg, does have some of the EECI questions and solutions available. Thus since students are not timed, they can easily search for these solutions while taking the EECI. So while some may argue that CIs should be given online, the author contends that giving the EECI via paper and pencil in in a controlled, timed testing environment provides greater validity in the results.

A third issue that is of concern is the way in which students at the three institutions were incentivized to take the concept inventory. Different methods were used that did appear to affect the overall average scores. Student motivation to do well is critical to obtaining valid results. Consistency in how the data is collected will be important in future studies of the EECI effectiveness. That is, researchers need to be able to control for the impact of various study factors on the EECI scores. This is a challenging but necessary effort when multiple institutions are involved.

# Conclusion and Future Work

Due to the increase in Cronbach’s alpha, the improved item difficulties and discriminations, and overall good results using the classical test theories on the EECI, it is concluded that this concept inventory continues to have great potential to be a valid and reliable assessment tool for testing a student’s knowledge of engineering economy concepts. In particular, Questions 1,2,4, 7-10,14-18, and 20 are showing good results as valid and reliable questions to assess engineering economic analysis knowledge. However, continued development of the instrument is required, including some question rewording as well as a focus on understanding the misconceptions that this tool can identify. It will be an excellent tool 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.

Future efforts to further refine the EECI will include reviewing and modifying the questions that continue to show high values on the difficulty measure (percent of students with the correct response). Misconceptions that can be determined by incorrect responses will be identified. This would be useful for instructors to know and use for corrective action in their courses. The author would also like to expand the distribution and use of the EECI at several more institutions to collect a larger dataset. To the extent possible, the instrument should be administered in a controlled testing environment to reduce the ability of students to search for solutions online. Once all of this has been done, additional methods for testing concept inventory validity that can be applied (item response theory, exploratory factor analysis) to the EECI and future work will include these.

# Acknowledgments

The author gratefully acknowledges Professor Kellie S. Grasman of the Department of Engineering Management and Systems Engineering at the Missouri University of Science and Technology and Professor Tish Pohl of the Industrial Engineering Department at the University of Arkansas for administering the EECI to their students and providing data for this research. This study was approved by the Institutional Review Board at the University of Pittsburgh as an exempt study, IRB PRO18080574.

# References

Brown, S., Lutz, B., Perova-Mello, N. and Ha, O. (2019) Exploring differences in Statics Concept Inventory Scores among Students and Practitioners. *Journal of Engineering Education*, 108, 119-135.

Bursic, K.M. (2017) Work in Progress – An Engineering Economy Concept Inventory. *Proceedings of the 2017 ASEE Annual Conference and Exposition*, Columbus, Ohio, <https://peer.asee.org/29138>.

Bursic, K. M. (2012) Does the Use of Clickers Increase Conceptual Understanding in the Engineering Economy Classroom? *Proceedings of the 2012 ASEE Annual Conference & Exposition*, San Antonio, Texas.

Bursic, K.M., Shuman, L, Besterfield-Sacre, M., Yildirim, T.P. and Siewiorek, N. (2010) Improving Conceptual Learning in Engineering Economy using Model-Eliciting Activities (MEAs*).* *Proceedings of the 2010 Industrial Engineering Research Conference,* Cancun, Mexico.

Deane, T., Nomme, K., Jeffery, E., Pollock, C. and Birol, G. (2016) Development of the Statistical Reasoning in Biology Concept Inventory (SRBCI). *CBE Life Sciences Education*, 15, 1-13.

Deane, T., Nomme, K., Jeffery, E., Pollock, C., and Birol, G. (2014) Development of the Biological Experimental Design Concept Inventory (BEDCI). *CBE Life Sciences Education*, 13, 540-551.

Dick-Perez, M., Luxford, C.J., Windus, T.L. and Holme, T. (2016) A Quantum Chemistry Concept Inventory for Physical Chemistry Classes. *Journal of Chemical Education,* 93(4), 605-612, DOI: <https://doi.org/10.1021/acs.jchemed.5b00781> .

Douglas, K. A. andPurzer, Ş. (2015) Validity: Meaning and relevancy in assessment for engineering education research. *Journal of Engineering Education*, *104 (2)*, *108*–*118*. [*https://doi-org.pitt.idm.oclc.org/10.1002/jee.20070*](https://nam05.safelinks.protection.outlook.com/?url=https%3A%2F%2Fdoi-org.pitt.idm.oclc.org%2F10.1002%2Fjee.20070&data=02%7C01%7Ckbursic%40pitt.edu%7C9d0f82b78faa4c7b859508d6b0a926c1%7C9ef9f489e0a04eeb87cc3a526112fd0d%7C1%7C0%7C636890637881826181&sdata=JXzY6ZD33gyw63nmBSo2eOYu%2Bg%2Fp2aYZsoBX58XZ0Qc%3D&reserved=0)*.*

Flynn, C.D., Davidson, C.I. and Dotger, S. (2018) Development and Psychometric Testing of the Rate and Accumulation Concept Inventory. *Journal of Engineering Education*, 107(3), 491-520.

Gleason, J. Bagley, S., Thomas, M., Rice, L., White, D. (2018) The Calculus Concept Inventory: a Psychometric Analysis and Implications for Use. *International Journal of Mathematical Education in Science and Technology*, DOI: [10.1080/0020739X.2018.1538466](https://doi.org/10.1080/0020739X.2018.1538466) .

Gray, G.L., Costanzo, F., Evans, D., Cornwell, P., Self, B. and Lane, J.L. (2005) The Dynamic Concept Inventory Assessment Test: A Progress Report and Some Results. *Proceeding of the 2005 ASEE Annual Conference and Exposition*, Portland, OR.

Hestenes, D., Wells, M. and Swackhamer, G. (1992) Force Concept Inventory. *The Physics Teacher*, 30, 141-158.

Jorion, Natalie; Gane, Brian D.; James, Katie; Schroeder, Lianne; DiBello, Louis V. and Pellegrino, James W. (2015) An Analytic Framework for Evaluating the Validity of Concept Inventory Claims. *Journal of Engineering Education*, 104(4), 454-496.

Lindell, R.S., Peak, E. and Foster, T.M. (2007) Are They All Created Equal? A Comparison of Different Concept Inventory Development Methodologies. *AIP Conference Proceedings* 883(14), <https://doi.org/10.1063/1.2508680> .

Madsen, A., McKagan, S. and Sayer, E.C. (2016) Best Practices for Administering Concept Inventories. *Cornell University Library*, <https://arxiv.org/abs/1404.6500>.

McFarland, J.L., Price, R.M., Wenderoth, M.P., Martinková, P., Cliff, W., Michael, J., Modell, H. and Wright, A. (2017) Development and Validation of the Homeostasis Concept Inventory. *CBE – Life Sciences Education*, 16(2), <https://doi.org/10.1187/cbe.16-10-0305>.

Ogunfunmi, R., Herman, G., Rahman, M. (2014), On the Use of Concept Inventories for Circuits and Systems Courses. *IEEE Circuits and Systems Magazine*, 3rd quarter.

Prince, M., Vigeant, M. and Nottis, K. (2012) Development of the Heat and Energy Concept Inventory: Preliminary Results on the Prevalence and Persistence of Engineering Students’ Misconceptions. *Journal of Engineering Education*, 101(3), 412-438.

Reed-Rhoads, T., Imbrie, P.K., Allen, K., Froyd, J., Martin, J., Miller, R.L., Steif, P., Stone, A. and Terry, R. (2007) Panel – tools to Facilitate Better Teaching and Learning: Concept Inventories. *Proceedings of the 37th ASEE/IEEE Frontiers in Education Conference*, Milwaukee, WI.

Sands, D., Parker, M., Hedgeland, H., Jordan, S. and Galloway, R. (2018) Using concept inventories to measure understanding, *Higher Education Pedagogies*, 3(1), 173-182, DOI: [10.1080/23752696.2018.1433546](https://doi.org/10.1080/23752696.2018.1433546) .

Savinainen, A. and Viiri, J. (2008) The Force Concept Inventory as a Measure of Students Conceptual Coherence. *International Journal of Science and Mathematics Education*, 6(4), 719-740.

Seitz, H, et. al. (2017) Development and Validation of the Microbiology for Health Science Concept Inventory. *Journal of Microbiology and Biology Education*, 18(3), DOI: [10.1128/jmbe.v18i3.1322](https://nam05.safelinks.protection.outlook.com/?url=https%3A%2F%2Fdoi.org%2F10.1128%2Fjmbe.v18i3.1322&data=02%7C01%7Ckbursic%40pitt.edu%7Cb36f9363f52941ef013808d6b0a3c3a0%7C9ef9f489e0a04eeb87cc3a526112fd0d%7C1%7C0%7C636890614744364793&sdata=q4k2GP4Z8Jk8J5XOtDlfqUmFiwKnK7%2FyYl23ncYZbyg%3D&reserved=0) .

Smith, J.I. and Tanner, K (2010) The Problem of Revealing How Students Think: Concept Inventories and Beyond. *CBE Life Sciences Education*, 9(1), 1-5.

Steif, P.S. and Hansen, M.A. (2007) New Practices for Administering and Analysing the Results of Concept Inventories. *Journal of Engineering Education*, 96(3), 205-212.

Steif, P.S. and Dantzler, J.A. (2005) A Statics Concept Inventory: Development and Psychometric Analysis. *Journal of Engineering Education*, 94(4), 363-371.

Stevens, A.M., et. al. (2017) Using a Concept Inventory to Reveal Student Thinking Associated with Common Misconceptions about Antibiotic Resistance. *Journal of Microbiology and Biology Education*, 18(1), DOI [10.1128/jmbe.v18i1.1281](https://nam05.safelinks.protection.outlook.com/?url=https%3A%2F%2Fdoi.org%2F10.1128%2Fjmbe.v18i1.1281&data=02%7C01%7Ckbursic%40pitt.edu%7Cea63282b3fad492e829808d6b0a44454%7C9ef9f489e0a04eeb87cc3a526112fd0d%7C1%7C0%7C636890616900503614&sdata=NXZNf2hYusb6%2BSYpacrChuQXrDrSXBDwXPibGeCsV9s%3D&reserved=0).

Stone, A, Allen, K., Rhoads, T.R., Murphy, T.J., Shehab, R.L. and Saha, C. (2003) The Statistics Concept Inventory: A Pilot Study, *Proceedings of the 33rd annual ASEE /IEEE Frontiers in Education Conference*, Boulder, CO.

Wage, K.E., Buck, J.R., Wright, C.H.G. and Welch, T.B. (2005) The Signals and Systems Concept Inventory. *IEEE Transactions on Education*, 48 (3), 448-461.

Wallace, C.S., Bailey, J.M. (2010*)* Do Concept Inventories Actually Measure Anything? *Astronomy Education Review*, 9(1).

# Appendix - EECI

Question 1

What is meant by the "time value of money"?

1. $1 today is worth more than $1 tomorrow.
2. The value of my savings account *always* increases over time.
3. The value of a sum of money depends on when it is received.
4. Both a. and b.
5. Both a. and c.
6. Both b. and c.
7. a., b., and c. are all true

Question 2

What is an "opportunity cost"?

1. The cost of not selecting a particular investment opportunity.
2. The overall cost of a particular investment opportunity.
3. The initial capital required for start up of an investment.
4. The incremental differences in cash flows of two alternatives.
5. The definition depends on whether it's with respect to a cost or investment alternative.

Question 3

Suppose you have the following two options: You can be paid $1000 today or $1050 at the end of the month. What would your decision depend on?

1. It is *always* more economical to take the money now.
2. It is *always* more economical to wait for the larger amount.
3. It depends on the interest that I can earn in one month.

Question 4

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

1. Independent
2. Dependent
3. It depends on how many competitors there are.
4. There is not enough information provided to determine this.

Question 5

Which of the following criteria can be considered in economic decision making?

1. Maximize Profits
2. Minimize Costs
3. Minimize the time required to meet objectives
4. Minimize environmental impacts
5. Maximize quality and safety
6. Only a. and b.
7. All of these can be considered economic decision making criteria.

Question 6

Variable costs are those that vary with respect to:

1. Price Charged
2. Volume or Demand
3. Interest Rate Used
4. Materials Used

Question 7

Per Unit Models, Indexes, Power Sizing Models, and Learning Curve Models are all tools used for:

1. Estimating which of two alternatives is cheaper
2. Determining which of two alternatives is more profitable
3. Determining the net present value of an investment
4. Estimating the cost of various alternatives
5. Estimating the future value of an investment

Question 8

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?

1. Machine A.
2. Machine B.
3. Both machines are equivalent.
4. There is not enough information provided to determine.

Question 9

A new water treatment plant will cost the city of Bradley $2,000,000 to build and $150,000 per year to operate for its 30-year life. Due to more efficient operation of the water plant, it is expected to benefit customers by lowering the cost of utility bills by $50 per customer per year. There are 6,000 customers that are billed in Bradley. A disbenefit of the plant is that it is expected to reduce the air quality in Bradley. This is estimated at $5 per resident per year and there are 18,000 residents of Bradley. If the current cost of capital is 5%, what is the Benefit Cost Ratio for this project and is it economically acceptable?

1. .01 yes acceptable
2. .75 not acceptable
3. .75 yes acceptable
4. .97 not acceptable
5. 1.3 acceptable
6. 1.3 not acceptable
7. None of these is correct

Question 10

Consider the following investment project with a useful life of 8 years:

* Initial Investment: $13,000,000
* Salvage Value: $500,000
* Annual Revenues $3,000,000
* Annual Expenses $900,000

By how much would the annual revenues have to be increased to make this an attractive investment if the investor’s required rate of return is 12%?

1. It's already an attractive investment, the revenues do not need to be increased.
2. About $300,000 per year
3. About $480,000 per year
4. More than $500,000 per year
5. There is not enough information provided to answer this question.

Question 11

The Pennsylvania Department of Transportation is considering adding additional highway lighting to an area of the Pennsylvania Turnpike that has seen an increase in traffic accidents in recent months. Because of the environment in this area, some wildlife will be adversely affected by the installation of the lighting fixtures. What factors are appropriate to include in the economic decision regarding whether or not to install the lighting?

1. Installation costs
2. Operating and maintenance costs
3. Estimated benefits of reduced traffic accidents
4. Costs of damage and injuries caused by accidents
5. Estimated environmental costs
6. Only a. and b.
7. a., b., and d.
8. All of these.

Question 12

You must help your company choose between two alternative energy systems for its new office building. The “green” design is much more expensive initially but promises long term operating savings and environmental benefits. You do an economic analysis per the company's specifications. If the expected return on the incremental investment in the green design versus the traditional design over a 10 year life is greater than the company’s usual minimum attractive rate of return, would you recommend the green alternative?

1. Yes, it's an economically attractive investment.
2. No, it’s not an economically attractive investment.
3. No, it's too long to wait for a return.
4. Not enough information is given to decide.

Question 13

If I deposit $1500 now into an account earning 5% compound interest per year, how much will I have at the end of 4 years?

1. $1575.00
2. $1800.00
3. $1823.26
4. $1914.42
5. $7593.75

Question 14.

If a company invests $20,000 to upgrade some equipment and prefers to earn a 15% return on its investments, how much money must the upgrade save per year over 5 years in order for the investment to be acceptable?

1. $4000
2. $4600
3. $5966
4. $8045
5. None of these are correct.

Question 15

Suppose you have an opportunity for an investment that requires $18,000 now. It is expected to return $3,000 per year for 9 years. There will be a salvage value of $1,000 at the end of the 9 years. If your company wishes to earn 10% on its investments, what is the net present value of this investment and should you invest (yes or no)?

1. -$6,200; No
2. -$723; Yes
3. -$299; No
4. $3,111; Yes
5. $6,200; No
6. $10,000; Yes

Question 16

As your cost of capital increases, the net present value of a simple investment will:

1. Increase
2. Decrease
3. Not enough information is provided to determine this

Question 17

In economic analysis, the term "depreciation" represents:

1. An accounting concept
2. The decline in an asset's value over time
3. A non-cash cost
4. All of the above

Question 18

A payback period is:

1. An exact economic analysis method
2. The number of time periods until cash inflows equal cash outflows
3. The rate of return at which an investment pays off
4. The time period during which the company starts making a profit
5. All of these.

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.

1. Lower, Good
2. Lower, Bad
3. Higher, Good
4. Higher, Bad

Question 20

Determine the equivalent uniform annual cost of a machine costing $4,000 with a life of 10 years and a salvage value of $300 (at year 10). Its operating expenses are $500 per year and your cost of capital is 12%.

1. $1208
2. $1191
3. $930
4. $900
5. None of these are correct.
1. ABET is the organization that accredits college and university programs in applied and natural science, computing, engineering and engineering technology. [↑](#footnote-ref-1)