# AC 2008-633: DEVELOPING AN INSTRUMENT TO MEASURE TINKERING AND TECHNICAL SELF-EFFICACY IN ENGINEERING

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# Developing an Instrument to Measure Tinkering and Technical Self-Efficacy in Engineering

**abstract**
An instrument to measure tinkering and technical self-efficacy was developed based on recommendations by Bandura. Self-efficacy is defined as an individual's beliefs about their ability to engage in activities that will result in successfully attaining specific goals. Thus, self-efficacy is context and skills specific rather than a global judgment of ability. Tinkering and technical self-efficacy in engineering are important because individuals with low self-efficacy in these areas are more likely to leave engineering majors independent of their levels of achievement. This is especially true for women. Consequently, the development of an instrument with good predictive power can be a useful tool for creating interventions for retention in engineering majors. The first phase of this study to develop a predictive instrument was to establish the content validity. During this phase, we used two open-ended questions asking the respondents to identify tinkering and technical skills. Eight hundred and seventy-one statements were obtained from a volunteer expert sample of 101 respondents. A count of statements with the same meaning was conducted and the most frequently mentioned were used to write questions. Approximately half were worded positively and half negatively. The tinkering and technical scales each consisted of 30 questions. The second phase of the study started with the development of a Likert-scale survey using these statements. The instrument was given in freshman design classes (n=84 students). Students were asked to rate themselves on a Likert scale from not descriptive of me (0) to very descriptive of me (5). The analysis indicated that students had moderate self-efficacy in terms of technical skills. Mean item scores were between 3.2 and 3.7. Students rejected negatively worded items on both scales as not descriptive with mean scores between 0 and 2. Students reported the least technical self-efficacy on the item "I can statistically model a process". Ratings on the tinkering scale included items with means scores above 4.0. These items were: "I can think outside the box", "I know how to use tools", I want to know how things work and how to make them better", and "I have the persistence to complete a project". The reliability of the tinkering scale was .87 and the reliability of the technical scale was .80. A factor analysis found three factors for tinkering. Factor one was labeled knowledge and experience, factor two creativity and curiosity and factor three knowledge and skills. There were also three factors for technical skills. Factor one was labeled technical knowledge, factor two understanding theories and models and factor three systems and how things work.

## introduction

The purpose of this research was to develop an instrument to measure tinkering and technical self-efficacy in engineering. Such an instrument has many uses among which are identifying students who many enter engineering with low self-efficacy or students whose self-efficacy declines as they study engineering. Efficacy measures must be tailored to specific domains and their specific skill sets. Data about students' tinkering and technical self-efficacy can then be used to design specific interventions. Such interventions are important because low self-efficacy in engineering is related to leaving engineering majors and is more common among women students than men students.

**literature review**
Self-efficacy is defined as an individual's beliefs about their ability to engage in activities that will result in successfully attaining specific goals. It is a set of context specific beliefs about competence rather than beliefs about general ability. It is not the number of skills you have but what you believe you can do in specific contexts. If a person feels that that they will not be self-efficacious, they avoid the task and more importantly avoid entire domains such as engineering. According to Bandura's theory [1], self-efficacy has four sources. These are enactive mastery experience, vicarious experience, verbal or social persuasion, and physiological and affective reaction. These factors can support or hinder one's self-efficacy depending on the nature of the task undertaken.

A number of researchers have looked at self-efficacy as it relates to careers and have found that self-efficacy is strongly related to both the range of career options as well as career preferences[2,3]. For example, Hackett [4] and Hackett and Betz [5] have examined mathematical self-efficacy because of the importance of quantitative skills to science, technology, engineering and technology careers. Their research indicates that individuals avoid some careers because of perceived mathematical ability rather than actual mathematical ability. Interest in specific aspects of a career and self-efficacy go hand in hand. Individuals with an high self-efficacy in science have a strong interest in theoretical abstract activities and individuals with an interest in technical activities have high self-efficacy in a variety of engineering subfields [6,7] .

When Lent, Brown & Larkin [8] compared self-efficacy to other theories of career choice such as Holland's [9] theory of fit between interests and occupational environment and Janis and Mann's [10] theory of decision making (considering consequences of alternatives) they found that self-efficacy was a better predictor. Neither the theory of fit nor the theory of decision making predicted academic achievement or career perseverance. Bandura [1] summarized the role of self-efficacy and career choice as follows. "…efficacy is a robust contributor to career development. It predicts the scope of career options seriously considered, occupational interests and preferences, enrollment in courses of study that provide the knowledge and skills for various careers, perseverance in difficult fields, academic success in chosen pursuits and even choice of cultural milieu in which to pursue one's occupational career." (p.427).

In the context of this work, tinkering self-efficacy refers to one's experience, competence, and comfort with manual activities. It is the confidence and belief in one's competence to engage in activities often associated with engineering such as manipulating, assembling, disassembling, constructing, modifying, breaking and repairing components and devices, (e.g. assembling a bicycle or taking apart a computer). Women's lack of experience in using tools and machinery and taking things apart and putting them together contributes to their low tinkering self-efficacy. Thus, tinkering experience favors men even when women have an interest in and an inclination towards technical fields. For example, Crismond[11] found that even academically well-prepared female students at a technical high school were fearful of simple mechanical devices (e.g. nutcrackers) and tentative in handling them when engaged in engineering design activities. In contrast, male students were confident and explored the devices to the fullest. In another study, Margolis and Fisher[12] found that female computer science majors at university did not, when playing with computers, take them apart and then reassemble them. In contrast to their male counterparts, tinkering was not something women chose to do in their free time while growing up and, as a consequence, they felt unprepared.

In the context of this work, technical self-efficacy refers to confidence and belief in one's competence to learn, regulate, master and apply technical academic subject matter related to success in engineering. Baumert, Evans, and Geiser[13] found that gender influenced technical self-efficacy, which in turn affected technical problem-solving. The women in their study had lower self-estimates of competence and technical problem solving scores than the men and attributed their failure to lack of ability rather than to lack of persistence. This is in sharp contrast to women's perceptions of their problem-solving abilities and persistence in mathematics, a foundational skill for success in engineering. In the case of mathematics, women believed they were better and more persistent problem-solvers than males[14]. However, even women in engineering majors who intended to go on to graduate school or who were already in graduate school expressed less efficacy in their technical abilities than did their male counterparts[15, 16]. Even male engineering students who drop out of engineering have greater technical self-efficacy than the females who graduate as engineer[17].

**research questions**

The research questions that guided this study were as follows.
What do experts in the engineering education community consider important tinkering and technical skills necessary for success in engineering?
What is the reliability of a self-efficacy instrument based on the tinkering and technical skills experts consider necessary for success in engineering?
What is the factor structure of a self-efficacy instrument based on the tinkering and technical skills experts consider necessary for success in engineering?
What is the self-efficacy of Freshman students in an engineering design course?

**method**

According to Bandura [1] general measures of self-efficacy have little or no relationship to an individual's efficacy beliefs as they relate to specific behaviors or specific domains such as tinkering. He recommends that the development of a self-efficacy instrument must draw on expert knowledge about what a person must do to be successful. This procedure establishes the validity of the instrument. Consequently, the first step in creating this tinkering and technical self-efficacy instrument was to survey experts in the field of engineering. The experts consisted of a volunteer sample of engineering faculty, students, and practicing engineers, who are members of ASEE. There were a total of 101 respondents (71 members of ASEE, 24 engineering students in a design course at a large university located in the southwest, and 6 engineering faculty at the same institution). The gender composition of the ASEE experts is unknown but there were two females in the ASU faculty group and four female engineering students. It is reasonable to expect that the gender composition of the ASEE group reflects that of the membership. Based on the ASEE membership, one can infer that the respondents were more likely to be educators than practicing engineers. Respondents were asked to respond electronically to two open-ended prompts. These prompts were; 1) List the characteristics of someone with good tinkering skills, and 2) List the characteristics of someone with good technical skills. No definitions of technical or tinkering skills were given to avoid biasing the respondents' answers. Responses ranged from one word, to phrases, to answers that were several sentences long.

The respondents wrote 598 statements for tinkering characteristics of engineers and 237 statements for technical characteristics of engineers with some characteristics listed by multiple respondents. A count of statements with the same meaning/theme was conducted and the most frequently mentioned were used to write the statements for the self-efficacy instrument. Half of the statements were worded negatively and half were worded positively which is one way to address response set as individuals take the survey. Statements represented what an individual was capable of doing and the statements had different task demands [1]. The statements were arranged on two scales with thirty statements on the tinkering scale and thirty statements on the technical scale. A 0 to 5 Likert scale was positioned next to each statement with 0 representing a statement that was not descriptive of the individual taking the survey to 5 very descriptive of the person taking the survey (Tables 1 and 2). Thus, the method used to gather and analyze data in the first phase of this research was grounded in the descriptive study survey approach.

The second phase of the study was quantitative and data was collected at the beginning of the semester. Eighty-four volunteer students in freshman engineering design courses (the first course in the engineering series) participated. Seventy-six students were male. Thirty-one reported their major as mechanical engineering, seven reported their major as civil engineering, seven reported their major as electrical engineering, four reported bioengineering, two reported industrial engineering, two reported chemical engineering and one reported environmental engineering. Twenty-six were undecided about their major. Twelve of the students were female. Eight of the females reported their engineering major as general or undecided. Three reported civil and one reported industrial engineering as their major. The students were asked to read the statements and rate the statements as not descriptive of themselves (0) to very descriptive of themselves (5). The instrument took approximately thirty minutes to complete. Negatively worded item were reversed scored. The reliability of the instrument was calculated to determine internal consistency or stability over time. A factor analysis was conducted to determine the factor structure of each scale. A factor analysis is the first step in determining the attributes related to a construct. The factor analysis is based on a matrix of individuals' scores for each item on the self-efficacy scales. It provides a picture of how items cluster (load) on the basis of how individuals responded to those items and how many clusters of items were found (factors). These factors may or may not be the same as the number of scales on an instrument that is under development and may not cluster the same items together as the instrument developer hypothesizes. Thus, a factor analysis provides guidance to how the final assessment should be organized and the items it should contain. It also provides a picture of the relationship of items because items that load on a particular factor are more strongly related to each other than items that load on other factors. This step provides a conceptual analysis of the different facets of tinkering and technical self-efficacy. In addition, responses to items with high or low ratings were identified.

**table 1 technical skills**

| **Statement** | **Not Descriptive Very Descriptive** |
|---|---|
| 1. I can statistically model a process. | 0----------1----------2----------3----------4----------5 |

| | |
|---|---|
| 2. I can not apply theoretical concepts to real-world problems. | 0----------1----------2----------3----------4----------5 |
| 3. I do not have data analysis skills. | 0----------1----------2----------3----------4----------5 |
| 4. I think practically. | 0----------1----------2----------3----------4----------5 |
| 5. I do not have written and oral communication skills. | 0----------1----------2----------3----------4----------5 |
| 6. I understand the relationship of theory and application. | 0----------1----------2----------3----------4----------5 |
| 7. I can develop/improve a product/system for manufacture of the product or implementation of the system. | 0----------1----------2----------3----------4----------5 |
| 8. I am not a logical thinker. | 0----------1----------2----------3----------4----------5 |
| 9. I know different ways to create a design. | 0----------1----------2----------3----------4----------5 |
| 10. I do not have engineering experience. | 0----------1----------2----------3----------4----------5 |
| 11. I can not logically prove something works. | 0----------1----------2----------3----------4----------5 |
| 12. I use available tools and knowledge. | 0----------1----------2----------3----------4----------5 |
| 13. I do not have a broad technical knowledge base. | 0----------1----------2----------3----------4----------5 |
| 14. I can formulate and analyze a model of a problem. | 0----------1----------2----------3----------4----------5 |
| 15. I can apply theory to real problems. | 0----------1----------2----------3----------4----------5 |
| 16. I am not a conceptual thinker. | 0----------1----------2----------3----------4----------5 |
| 17. I understand how parts work together to make the whole operate. | 0----------1----------2----------3----------4----------5 |
| 18. I do not have technical understanding of fundamentals and the ability to use this knowledge. | 0----------1----------2----------3----------4----------5 |
| 19. I can not summarize the key points of a technical problem with simple language. | 0----------1----------2----------3----------4----------5 |
| 20. I can do back-of-the-envelope calculations to show workability. | 0----------1----------2----------3----------4----------5 |
| 21. I can use a computer as a tool. | 0----------1----------2----------3----------4----------5 |
| 22. I do not have broad experience with equipment. | 0----------1----------2----------3----------4----------5 |
| 23. I do not understand the theory behind how something works. | 0----------1----------2----------3----------4----------5 |
| 24. I do not know design concepts. | 0----------1----------2----------3----------4----------5 |
| 25. I understand the concepts behind how something works. | 0----------1----------2----------3----------4----------5 |
| 26. I can parse problems and develop a path to a solution. | 0----------1----------2----------3----------4----------5 |
| 27. I understand and can apply mathematical concepts to a problem. | 0----------1----------2----------3----------4----------5 |
| 28. I do not have broad knowledge in fields | 0----------1----------2----------3----------4----------5 |

| | |
|---|---|
| beyond engineering. | |
| 29. I can not communicate ideas and concepts to others. | 0---------1---------2---------3---------4---------5 |
| 30. I have knowledge & technical skills to create mechanisms/devices. | 0---------1---------2---------3---------4---------5 |

**table 2 tinkering skills**

| Statement | Not Descriptive Very Descriptive |
|---|---|
| 1. I have more experience than knowledge. | 0---------1---------2---------3---------4---------5 |
| 2. I am persistent and willing to try new processes to get an invention to work. | 0---------1---------2---------3---------4---------5 |
| 3. I have a long history of tinkering on personal development projects. | 0---------1---------2---------3---------4---------5 |
| 4. I have the knowledge and technical skills to create mechanisms or devices. | 0---------1---------2---------3---------4---------5 |
| 5. I do not have spatial sense. | 0---------1---------2---------3---------4---------5 |
| 6. I do not consider solutions before taking things apart. | 0---------1---------2---------3---------4---------5 |
| 7. I am inquisitive. | 0---------1---------2---------3---------4---------5 |
| 8. I can think outside the box. | 0---------1---------2---------3---------4---------5 |
| 9. I can not decipher mechanisms uncovered in tinkering. | 0---------1---------2---------3---------4---------5 |
| 10. I do not work well with my hands. | 0---------1---------2---------3---------4---------5 |
| 11. I try to understand how things work in order to fix problems. | 0---------1---------2---------3---------4---------5 |
| 12. I do not have a passion to create. | 0---------1---------2---------3---------4---------5 |
| 13. I know how to use tools. | 0---------1---------2---------3---------4---------5 |
| 14. I do not understand technical drawings such as wiring diagrams. | 0---------1---------2---------3---------4---------5 |
| 15. I can troubleshoot technical problems. | 0---------1---------2---------3---------4---------5 |
| 16. I have deductive reasoning skills. | 0---------1---------2---------3---------4---------5 |
| 17. I know enough about a system to explore but lack technical depth. | 0---------1---------2---------3---------4---------5 |
| 18. I do not have imagination. | 0---------1---------2---------3---------4---------5 |
| 19. I am not afraid to take things apart to find out how they work. | 0---------1---------2---------3---------4---------5 |
| 20. I want to know how things work and how to make them better. | 0---------1---------2---------3---------4---------5 |
| 21. I do not know what tools are available. | 0---------1---------2---------3---------4---------5 |
| 22. I am not curious. | 0---------1---------2---------3---------4---------5 |
| 23. When I look at something I can not imagine how it works. | 0---------1---------2---------3---------4---------5 |
| 24. I can not build something with my | 0---------1---------2---------3---------4---------5 |

| | |
|---|---|
| hands. | |
| 25. I have creative abilities. | 0---------1---------2---------3---------4---------5 |
| 26. I can not take things apart and put them back together. | 0---------1---------2---------3---------4---------5 |
| 27. I have the persistence to complete a project. | 0---------1---------2---------3---------4---------5 |
| 28. I do not have mechanical intuition. | 0---------1---------2---------3---------4---------5 |
| 29. I do not have tinkering type hobbies. | 0---------1---------2---------3---------4---------5 |
| 30. I can not visualize a product from the description of a problem. | 0---------1---------2---------3---------4---------5 |

**results**

The Spearman-Brown reliability coefficient for the technical scale was .80 and the Spearman-Brown reliability coefficient for the tinkering scale was .87. This indicates that the test has median reliability and reasonable internal consistency or stability over time especially for a thirty item scale. Perfect reliability would be a coefficient of 1. No reliability would result in a coefficient of .0. There were three clear factors for the technical scale accounting for 41% of the variance. All but one of the negatively worded items on the technical scale loaded on factor one. This factor was labeled technical knowledge because it consisted of items addressing these competencies. The second factor was labeled understanding theory and models because it consisted of items addressing these competencies. The third factor was labeled systems and how things work because it consisted of items addressing these competencies. There were also three clear factors for the tinkering scale accounting for 44% of the variance. Again, all but two items loaded on the first factor. This factor consisted of most of the negatively worded items and was labeled knowledge and experience because it consisted of items addressing these competencies. The second factor was labeled creativity and curiosity because it consisted of items addressing these competencies. The third factor was labeled knowledge and skills because it consisted of items addressing these competencies.

The factor structure of the tinkering and technical scales indicated that the original scale configurations may need revision and that a larger sample is needed for further analysis before the final scale configurations can be decided upon.

The mean of the sample for each item was calculated. Splitting the score range into two components of 0-2 low self-efficacy and 3-5 high self efficacy for positively worded items and 0-2 high self-efficacy and 3-5 low self-efficacy for negatively worded items reveals some interesting patterns. An examination of the means of the individual items indicated that this was a strongly efficacious group. There were no items on the tinkering scale that indicated that the students did not feel efficacious. All negatively worded items fell below two indicating a high level of efficaciousness. All positively worded items were above 3.5 also indicating a high level of efficaciousness. Items on the tinkering scale with means scores above 4.0 were: “I can think outside the box”, “I know how to use tools”, I want to know how things work and how to make them better”, and “I have the persistence to complete a project”. Students did not feel quite as efficacious about their technical skills. However, beliefs about lack of efficacy were limited to the areas of statistically modeling a process, engineering experience, broad technical knowledge, and the ability to do back of the envelop calculations. Students reported the least technical self-efficacy on the item “I can statistically model a process”.

**conclusions**

The validity and reliability of the instrument appears to be sufficiently well established to merit moving forward with the refinement of the instrument. The factor analysis also indicates that there is merit in further refinement of the instrument and that the scales are tapping into important efficacy constructs. The loading of items (the correlation of the item to other items on a factor) on each factor has face validity in that they can be readily identified as being logically related. The first construct on the technical scale, technical knowledge, reflects a high degree of belief in technical competencies needed to be successful in engineering and a rejection of statements that suggest that students can not accomplish technical engineering tasks because they lack the knowledge to do so. The second construct of the technical scale, theories and models, makes sense given that both theories and models are used to explain natural and man made phenomena. The third construct of the technical scale, systems and how things work, are also related in that understanding how the parts work is critical to understanding a system in its entirety.

The first construct of the tinkering scale, knowledge and experience, is similar to the first construct on the tinkering scale, although the knowledge realm is derived from real world experiences rather than the technical knowledge derived from academic experiences. Again, students reject statements that suggest that they do not have the knowledge and experience to successfully accomplish engineering tasks. The second construct of the tinkering scale, creativity and curiosity, is an interesting combination and suggests a reciprocal relationship between curiosity and creativity. The third construct of the tinkering scale is knowledge and skills. This combination of statements suggests that students have procedural knowledge. That is, knowledge about how one goes about tinkering.

The data also raises several questions that will direct further development of this instrument. The first question is whether the factor structure is stable over a larger sample or with a sample of more advanced engineering students. We are currently addressing this issue as we collect additional data for analysis. The second question is whether the high levels of self-efficacy found in this study is a function of the time at which the data was collected (beginning of the semester) or the point in the students’ academic career (freshman). Data with older students and data collected at the beginning and end of courses will be obtained to address these questions. There is also the question of whether the structure is the same for male and female students. In this study we were unable to answer that question because of the small number of women in the sample. Finding a sample of women that is large enough to conduct factor analysis is a challenge that requires creative solutions such as data collection over multiple years or across institutions.

In addition, the instrument requires further validation to address some of the questions raised. Consequently, further work in validating this instrument will compare the responses on this instrument to other self-efficacy instrument currently in the literature. Further research will allow for refinement of an instrument that has the potential contribute to engineering education by providing educators with another tool to support and retain talented students who are at risk of leaving engineering.

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