Using an Engineering Design Process Portfolio Scoring Rubric to Structure Online High School Engineering Education

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An Engineering Design Process Portfolio Scoring Rubric and E-Portfolio System for Structured K-12 Engineering Education (Work in Progress)

Introduction

With the increasing U.S. emphasis upon science, technology, engineering, and math (STEM) education, many primary and secondary schools would like to add engineering to their curricula.[1] These schools are challenged though, because engineering education credentialing pathways for teachers are, at present, largely nonexistent, and K-12 engineering curricula are actively being defined, debated, and considered for implementation.[2, 3] Still, recent years have witnessed a strong upsurge in discussion and activity around these challenges, and efforts are underway to:

- Provide teacher training (e.g., The Infinity Project, Project Lead the Way),
- Define K-12 engineering curricula and standards (e.g., Engineering is Elementary, Engineering by Design, TeachEngineering, the Next Generation Science Standards, and state efforts like those in Massachusetts and Texas), and
- Motivate K-12 students to engage with engineering (e.g., the FIRST programs, the Technology Student Association activities, the SeaPerch challenge).

As a result of such efforts, engineering is making its way into the K-12 education arena as a distinct, identifiable body of knowledge and skills.

To ensure that the correct elements of engineering are woven into the K-12 curricula, it is important to consider exactly what engineering is. One concise and useful definition of engineering is "the iterative design and the optimization of materials and technologies to meet needs as defined by criteria under given constraints. Engineers use systematic processes, mathematical tools and scientific knowledge to develop, model, analyze and improve solutions to problems."[4] As a field of study and a profession, engineering has been taught by higher education and practiced by industry for nearly 200 years. While faculty have long taught engineering and companies have created advanced technologies using the engineering design process, today's challenge is to articulate engineering so that K-12 educators and students can consider, understand and begin to master it as well.

The words of the engineering definition given above are at first glance understandable and familiar. Yet, those words encapsulate a complex and deep intellectual endeavor not well understood or formally practiced by many. To allow engineering to be taught effectively across the K-12 education spectrum, particularly by teachers who themselves may not have studied or practiced engineering, it is critical to articulate the important elements of engineering and to provide specific assessment criteria that can be used to evaluate student proficiency with each element. As the elements and related assessment criteria are clearly defined, teachers can begin to consider lesson plans that teach engineering concepts at the appropriate level for their students. This paper describes an ongoing effort to:

- Identify engineering design as a cornerstone of K-12 engineering education,
- Define expected learning outcomes for students studying engineering design,
- Develop an electronic portfolio system where students can store work and demonstrate knowledge and mastery of engineering design-related skills, and

- Construct, refine, validate, and assess the reliability of an assessment scoring rubric based upon the major elements of the engineering design process.

Focusing upon engineering design and defining learning outcomes

When the project described here began in 2004-2005, an early topic of discussion was the focus of high school engineering studies. If engineering was to be infused into high school curricula, what aspects of the field's body of knowledge and activity should students study and begin to master? Through consultation with a host of stakeholders from K-12, higher education, and engineering professional societies and review of over thirty college and university Introduction to Engineering syllabi, it was concluded that high school students would be well-served to focus their studies upon engineering design.[5]

Having resolved to focus upon engineering design, the team turned its attention to articulating learning objectives (i.e., competencies) that students should master during study of engineering design. What precisely do students need to know? Quickly, it became apparent that the well-established steps of the engineering design process[6, 7, 8] lent themselves quite naturally to being used as the framework to which different engineering competencies could be attached. During practice of the engineering design process (Figure 1) individuals should be able to:

1. *Identify* a significant challenge and *specify* a set of requirements that a successful engineering response to the challenge (i.e., a solution) should achieve,
2. *Imagine* a diverse set of possible solutions to the challenge and use systematic processes to *select* the most promising solution,
3. *Define* the solution using scientific knowledge, mathematical techniques, and technology tools and *evaluate* it via one or more prototypes,
4. *Report* the findings of the evaluation and *conclude* whether the prototyped solution can be expected to achieve the previously specified requirements, and
5. *Reflect* upon the process and *recommend* iteration or implementation of the solution.

Figure 1 **The activities of the engineering design process**. The engineering design process is a structured, deliberate sequence of activities intended to deliver a top quality solution to an identified challenge when well executed.

The engineering design process defines a sequence of activities that require important engineering knowledge and skills in order to complete professionally. For individuals undertaking engineering design, what level of capability must they demonstrate for each process element in order to be considered competent in that element's knowledge and skills? As the team sought to answer this question it recognized a critical problem. No generalized assessment tools existed that could be used to benchmark and score student work in engineering design.[5] Having recognized this gap, the team turned its attention to the development of a set of assessment scoring rubrics, one for each major element of the design process, that would allow student performance in the underlying knowledge and skill areas to be reliably and repeatably rated.

Constructing scoring rubrics for engineering design work

Initial development of a set of engineering design process scoring rubrics was done based upon the collective engineering design experience of many team members and associates and in consultation with experts in performance-based assessment.[5] For each major element of the engineering design process, a rubric was defined that articulated the knowledge and skills needed to complete that element and categorized the quality of work expected to be provided as evidence of the knowledge and skills. Collectively, the set of rubrics are referred to as the Engineering Design Process Portfolio Scoring Rubric (EDPPSR). Each individual rubric within the EDPPSR is structured to delineate six scoring levels[5]: 0 (no evidence), 1 (novice), 2 (developing), 3 (proficient), 4 (advanced), 5 (exemplary). These levels and the associated rating descriptors were developed from a draft-state rubric into a provisional set of rubrics in late 2010 and, after being piloted, were further revised in August 2011 to take their current form.[9, 10] Rubrics were created for twelve distinct elements of the engineering design process and two aspects of presenting engineering design work in a professional form, as a portfolio:

- Component I: Presenting and Justifying a Problem and Solution Requirements
    - Presentation and justification of the problem
    - Documentation and analysis of prior solution attempts
    - Presentation and justification of solution design requirements
- Component II: Generating and Defending an Original Solution
    - Design concept generation, analysis, and selection
    - Application of STEM principles and practices
    - Consideration of design viability
- Component III: Constructing and Testing a Prototype
    - Construction of a testable prototype
    - Prototype testing and data collection plan
    - Testing, data collection and analysis
- Component IV: Evaluation, Reflection, and Recommendations
    - Documentation of external evaluation
    - Reflection on the design project
    - Presentation of a designer's recommendations
- Component V: Documenting and Presenting the Project
    - Presentation of the project portfolio
    - Writing like an engineer

As team members articulated these rubrics, they considered how the rubrics would be refined, validated and disseminated to educators for use. Rubric refinement and validation would require access to many student exhibits in a broadly uniform format that could be scored. In terms of educator use, the rubrics could be used by individual instructors to evaluate the work of their own students. They could also form the basis for other forms of assessment, including, but not limited to, an Advanced Placement exam in engineering and college / university self-study reports for ABET.[5, 11, 12] While considering the many possible uses of the rubrics, the team concluded that all users would benefit from a common repository where student design work could be stored and through which students could grant access for review. This realization prompted the team to consider development of an internet-based, web-browser accessible electronic portfolio (e-portfolio) system.

Developing an e-portfolio system as a repository for engineering design work

In education, a portfolio is an organized collection of artifacts intended to exhibit a student's work and capability in a given area.[13] E-portfolios are simply digital collections of such artifacts. As this research team was concluding that an e-portfolio system would be a useful repository for student design work in engineering, others seeking to advance engineering and technology education were reaching the same conclusion and, in fact, had already begun to build such a system. Through their own efforts, Project Lead the Way had created an initial e-portfolio system, the Innovation Portal, to support their own initiatives, and its capabilities were well suited to support the efforts of the education initiative described here.

Today, Project Lead the Way continues to develop the Innovation Portal, and its website developers have now organized the Innovation Portal e-portfolio site around the EDPPSR assessment tool. The site is open to all users via free accounts. Thus, as students in various formal and informal education settings work on aspects of engineering design, they may create accounts on the Innovation Portal and upload examples of their work for each aspect of the engineering design process. Then, if they wish to do so, students may grant access to their work to teachers or other outside reviewers. By the end of 2013, nearly 16,000 users had created accounts on the Innovation Portal (Figure 2), thereby generating a large repository of student design work from which research team members are endeavoring to solicit materials for assessment as part of the rubric refinement, validation, and reliability verification process.

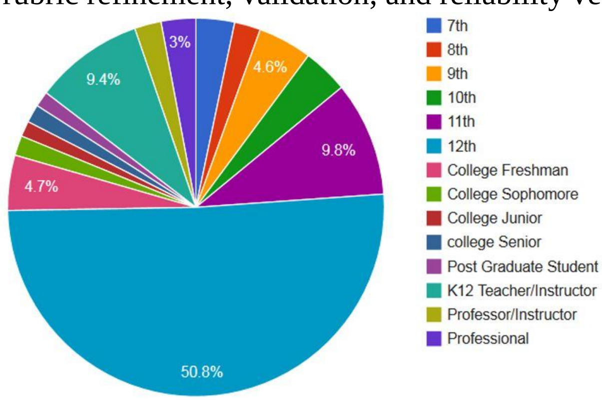

Figure 2 **Distribution of users of the Innovation Portal e-portfolio system.** Most of the accounts have been created by high school seniors, reflecting use of the portal as a host site for capstone design projects undertaken by Project Lead the Way students.

Refining, validating, and preparing the EDPPSR for use

Since the fall of 2011, the research team has drawn together a set of institutional review board approved e-portfolio scoring workgroups as part of NSF-funded efforts to validate the EDPPSR. For the scoring workgroups conducted so far, scorers have been consistently drawn from a pool of individuals engaged in engineering education (high school through college) who are at least broadly familiar with the EDPPSR. The long-term goal of these workgroup meetings is to determine the validity and reliability of the EDPPSR's individual rubrics. With these initial workgroups, the process initiated during the pilot scoring in 2011 (to answer key questions about the EDPPSR) has continued; these questions include consideration of whether or not:

- Important elements of the engineering design process have been neglected,
- The engineering design process has been optimally divided into elements for scoring or if a different grouping should be considered,
- The descriptors for the 0-5 score levels on each rubric are complete, non-repetitive, and unambiguous, and
- The descriptors lead to perceived errors in assigned scores (i.e., cognitive dissonance).

Formal and systematic study of inter-rater reliability using the EDPPSR has not yet taken place, but plans for that study are well underway and will address the question of whether the rubrics are sufficiently well-defined to allow for consistent rating of student submissions. Ultimately, analyses of the validity and reliability of the EDPPSR will determine the degree to which the rubrics are indeed evaluating what they suggest they can. The analyses should answer the question, "Does the rubric accurately indicate a student's mastery of the key engineering knowledge and skills associated with each element of the design process?"

As a precursor to validation and reliability studies, the scoring workgroups conducted so far have been intended to:

- Develop a group of scoring experts familiar with the EDPPSR and the use of its rubrics to evaluate student work,
- Identify consistently rated student submissions for each major engineering design process element that can serve as training resources for future project work, and
- Generate feedback from which annotations can be developed that help to explain scoring decisions and can be used as training materials for future project work and also as instructional resources.

Ultimately, the research team needs to locate and score examples of student work across the entire 0-5 scale of each major engineering design process element for training purposes. At present, annotated examples of scored portfolio entries for at least some score points, across all elements, have already been posted on the Innovation Portal. Students and teachers thus have access to resources that may provide greater insight into engineering design and into the criteria by which their portfolios may be evaluated. This greater insight will allow them to generate more successful portfolios that can be used to train the raters who will participate in the upcoming inter-rater reliability study and other activities pertinent to the EDPPSR.

Additional impacts

While the current work of this project is focused upon high school engineering design work, the rubrics reported here could ultimately be applied much more broadly. As noted earlier, prior to development of the EDPPSR, no generalized assessment tools existed that could be used to benchmark and score work in engineering design. The EDPPSR was developed as an assessment rubric for anyone engaged in engineering design work, from someone demonstrating no knowledge of the field to someone capable of exemplary work. So, the EDPPSR rubric could be used as a guide for engineering design work in elementary, middle school, high school, college, and professional realms. While a student in elementary school might be expected only to achieve scores of 1 for work related to each element of the design process, a graduating engineer from college, might be expected to demonstrate consistent scores of 4 across the elements. Thus, much work remains to be completed before the EDPPSR is a fully functional assessment rubric. Yet, investments of effort in continued development appear worthwhile given the far reaching implications of the work.

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