AC 2011-1405: ANALYSIS OF THE BARRIERS, CONSTRAINTS AND ISSUES FOR DUAL CREDIT AND / OR ADVANCED PLACEMENT PATHWAY FOR INTRODUCTION TO ENGINEERING / DESIGN

Leigh R Abts, Ph.D., University of Maryland College Park

Dr. Abts received his Bachelor's of Science in 1973 from Brown University, and his Ph.D. in Engineering in 1982 from Brown University. Currently, Dr. Abts holds a joint faculty appointment as a Research Associate Professor in the College of Education and the A. James Clark School of Engineering at the University of Maryland at College Park.

Analysis of the Barriers, Constraints and Issues for Dual Credit and / or an Advanced Placement® Pathway for Introduction to Engineering / Design

Abstract

Over the past five years a national research effort has elicited the opinions, attitudes and expertise of individuals and institutions engaged in engineering education through focus groups and expert interviews; and has conducted a limited number of case studies to explore the need, the barriers, the feasibility and the alternatives for a pre-college student to earn transferable, undergraduate credit for *Introduction to Engineering* or as an alternative, *Introduction to Design*.

This paper reviews the research and the field studies to date with respect to the following issues, constraints, and factors that can impact the preparation of students and instructors, the development of the courses (or course of study), and the transferability of credit (either through Advance Placement or dual-enrollment), such as:

- Existing standards that define and guide the secondary and undergraduate curriculum for Introduction to Engineering courses;
- Existing preparatory pathways for students to an Introduction to Engineering course; Comparative analysis of Introduction to Engineering courses relative to learning goals, teaching of Engineering core competencies, and performance benchmarks;
- The bridging of formal classroom courses to co-curricular, informal activities through portfolio reports and assessments;
- The need for a "reference" Introduction to Engineering (or Introduction to the Design Process) curriculum as a model for a dual enrollment (secondary and undergraduate credit);
- The importance of the preparation of secondary teachers in Introduction to Engineering and design course content and problem-solving, and performance assessment; and
- The importance of an assessment tool kit that includes rubrics for the design process and problem-solving and that utilizes an electronic portfolio.

A recent focus group and expert interviews have indicated that use of a design process rubric could form the initial reference framework for the learning, teaching and performance guidelines not only for those courses, but also for courses of study related to the *Design Process,* such as a senior-level Capstone Design Project. The creation of a reference Design Process Rubric would begin to lay the foundation to address some of the barriers to both an advance placement and / or for a dual-enrollment course (secondary and undergraduate credit).

Introduction

The work reported in this paper began with the **S**trategies for **E**ngineering **E**ducation **K – 16 (SEEK-16)** Summit held on February 21 and 22nd, 2005 at the National Academy of Engineering. As a direct result of SEEK-16: (1) funding was provided by several National Science Foundation (NSF) awards; (2) a research program was conducted to study the rationale, the feasibility and the requirements for an Advanced Placement (AP®) in Engineering course of

study; (3) limited field studies were conducted; and (4) development of an initial, generalized rubric for the design process through additional funding by the NSF and the Kern Family Foundation. Overall, the effort was segmented into three phases beginning with the research to elicit the opinions, attitudes individual experts and focus groups and concluding with the development of a draft Engineering Design Process Portfolio Scoring Rubric (EDPPSR).

In summary, from 2005 up to the present, the research and a pilot study explored:

- The need for an AP® in Engineering;
- The inclusion of students from a range of learning styles and abilities;
- The potential content for the AP® Engineering course of study;
- The requisite scope of the professional development for teachers;
- The sentiment of higher education faculty to awarding undergraduate credits in Engineering to secondary students;
- The relevance to the College Board's Vision and Mission for an Engineering AP®;
- The possibility of an alternative, dual-enrollment course for secondary students to earn high school and undergraduate credit;
- The utilization of a portfolio to present student work for review and utilize a scoring system modeled after the AP® for Studio Art;
- The utilization of a portfolio to capture, report and used to score student engineering design project activities, regardless of educational setting – e.g., formal or informal;
- The process to review and score the portfolio work of a student; and
- The potential of the portfolio to impact the considerations for undergraduate admission and / or undergraduate placement credit.

The effort to date has led several findings, as illustrated by the following:

- Finding for Higher Education, as summarized in a memo by the College Board in 2007: Colleges were reluctant, at this point, to believe that a college-level engineering course could be successfully offered by high schools, and indicated a lack of willingness to support a program that would allow a high school student to receive, for a qualifying exam grade, advanced placement into a higher-level engineering course at the university. However, university representatives did indicate a high level of interest in a high school program that would prepare students for a successful enrollment in college engineering courses.[1]

- Finding for Secondary Education, as summarized in a memo by the College Board in 2007: While a small number of secondary schools are currently capable of delivering engineering courses comparable to the entry-level college engineering course, most secondary schools need assistance in developing and offering a consistently high quality pre-college engineering course that would help students develop a solid foundation for successful enrollment in the entry-level college engineering course.[1]

- Finding, as summarized by the author for Secondary and Higher Education. No single framework exists that could capture the design process fully or well, and benchmark each element of the process to a commonly accepted set of referenced artifacts. Compounding the challenge of constructing of a stepwise, artifact driven framework is that engineering design is typically practiced over time as a complex and iterative process. For both

novice and advanced students, learning and applying the design process is often cumulative, with many informal and formal programmatic opportunities to practice essential elements.

Current Situation

The evidence is growing regarding the relationship of engineering practices to the learning of mathematics, science and technology (STEM) concepts.[2] There is a growing consensus that if all students were immersed in the concepts of engineering design and in problem-based learning, their interest in STEM will increase. [3,4,5,6,7,8] The National Governors Association (NGA) in defining *STEM Literacy* has emphasized, "[The] hallmark of a STEM classroom is an emphasis on design and problem-solving..." [9] The attributes of a STEM-literate students have been further defined in various reports as individuals who are: (1) problem-solvers – able to frame and apply understanding to solve problems; (2) inter-disciplinary thinkers – able to think across disciplines; (3) self-reliant – able to set their own pace of study and work within specified time frames; and (4) technology-capable – able to understand and apply technology to master skills and to solve problems. [11,12,13,14,15] These attributes parallel those of a successful engineering student.

According to Wolff-Michael Roth, "The major educational goal in engineering design is that students can develop two important kinds of knowledge necessary for making increasingly intelligent choices and decisions: (a) deep familiarity within a specific domain [content]; and (b) strategies for bringing structure to complex and ill-defined [that is, unstructured] problem settings or systems level thinking skills." [16] A number of studies have demonstrated that students' participation in engineering design activities can significantly advance their academic, creative abilities, and cognitive functioning. [17,18,19]

The design process is typically depicted as: 1) a series of steps to follow; 2) a combination of steps embedded in case studies or methodologies of instruction; or 3) an aspects of an assessment process limited to a subset of grade levels, programs, classroom activities and / or assessment processes.

For example, in *Learning Science through Design,* Haury[20] generalizes the design process as: 1) identifying and defining problems**;** 2) gathering and analyzing information; 3) determining performance criteria for successful solutions; 4) generating alternative solutions and building prototypes; 5) implementing choices; and 6) evaluating outcomes. Conceiving – Designing – Implementing – Operating (CDIO) has added granularity as illustrated, by the step Experimentation and Knowledge Discovery that is broken down into the smaller increments: (a) Hypothesis Formulation; (b) Survey of Print and Electronic Literature; (c) Experimental Inquiry; and (d) Hypothesis Test, and Defense. [21]

In applying the design process, textbooks, reports and guides often provide descriptive discussions of design detailing the importance and often provide case studies to illustrate appropriate instruction and practice of design, as in: *Improving Engineering Design* [22]; *Coming to Terms with Engineering Design [23]; Engineering Problem-solving for Mathematics, Science and Technology Education* [24]; *Designing Communities* [16]; *Engineering Design* [25]*; Engineering Your Future* [26]*; and BIODESIGN* [27].

However, as also referenced in the NGA report, the design process is an intellectually "messy" process. Such a process does not align well with current performance evaluation practices and to score a student student's project-based work, especially if implemented in formal and informal settings. Hence, a critical barrier to an AP® Engineering course of study is the reporting and evaluation of a secondary student's design-based project(s) – an often important aspect of an undergraduate Introduction to Engineering Course.

Currently, a student's transcript is the most widely applied and utilized model for representing a student's learning and practice of STEM concepts. The transcript provides a series of one-dimensional, snapshots (grades) aggregated as a Grade Point Average – GPA, and is sometimes supplemented with other data such as SAT® or ACT® scores. The assessment process that is most often used to generate a transcript grade is the administration of multiple-choice tests, inferences from which have, for the past century, been central to the definition of competency. Given the potential richness and complexity of evidence of proficiency in the engineering design process, however, portfolio assessment offers a promising alternative.

While there is no single definition of an assessment portfolio, among features that many portfolio-based programs, both past and ongoing, have in common is their understanding that a portfolio is "a purposeful collection of student work that exhibits to the students (and/or others) the student's efforts, progress, or achievement in given area(s). The collection must include student participation in selection of portfolio content; the criteria for selection; the criteria for judging merit; and evidence of student self-reflection." [28] Archbald and Newmann [29], and Paulson, Paulson, and Meyer [30] were among the first proponents of the idea that students should be active developers and assessors of their own portfolios, and there is general agreement in the assessment community that students must take the lead in documenting their learning. Towards that end, most portfolio assessment systems provide students at minimum with a general outline or "menu" of contents (suggested and/or required entries) and the evaluative criteria that will be applied.

The AP ® Studio Art portfolio assessment has served as a critical model in conceptualizing a considerably open-ended portfolio assessment that will capture the engineering design process. That program was built on a foundation of scoring research that provided a framework for effectively evaluating nearly thousands of portfolios a year[31]. In reference to the Studio Art portfolio, Wolf, Glenn, and Gardner[32] have noted:

> …students have an almost unfettered choice of media, themes, and styles. But the AP program provides a great deal of information about the qualities students need to display in their work, what they need to assemble as work products, and how raters will evaluate them. This structure allows for a common argument, heads off alternative explanations about unclear evaluation standards in the hundreds of AP Studio Art classrooms across the country, and, most happily, helps students come to understand the nature of good work in the field.

However, the AP® pathway is not the only one available to students to engage in programs that both prepare them to become college ready, and to earn college credit.

Traditionally, college readiness has been defined as "the level of preparation a student needs in order to enroll and succeed – without remediation – in a credit-bearing general education course

at a post-secondary institution" and success as "completing entry-level courses at a level of understanding that makes it possible for the student to consider taking the next level course in the subject area." [33] Dual enrollment (high school and undergraduate credit) has been demonstrated as an academic pathway that encourages students to become college ready and to persist in their higher education studies. [34,35,36,37]

Students who participate in dual enrollment have been shown to be more likely to complete high school, enroll in college, bypass remedial coursework, make timely progress toward a college degree, and incur less college expenses. [35,36,37] Currently, dual enrollment is available in the majority of high schools[38] and colleges. [39] However, only five percent of high school students report taking college courses and most programs serve only higher achieving students. [39,40] In addition, dual-enrollment offers benefits for career and technical education (CTE) students as well as secondary students. For example, one study found that CTE students in dual enrollment compared to those not in dual-enrollment were more likely to pursue a bachelor's degree. [35]

Overview of Studies

In the first series of studies, the investigators conducted focus groups across the United States, interviewed experts by telephone, piloted a test project with secondary students, coordinated development and refinement of a Design Process Rubric in consultation with experts (teachers, faculty, portfolio and performance), held review meetings, and reported to NSF, the College Board, and the Kern Family Foundation under Institutional Review Board approved protocols.

Within the scope of this research study, the goals were to:

- Ground the process in evidence-based research;
- Develop inclusion strategies and tactics for all students;
- Specify the learning goals, content, benchmarks and indicators for an AP®-like (or for dual-enrollment) course(s) in Introduction to Engineering and/ or Introduction to Engineering Design;
- Cross-reference the benchmarks and indicators to existing standards (i.e. American Association for the Advancement of Science's Project 2061, the International Technology in Education Association's (ITEA) Technology Literacy Benchmarks, National Science Education Standards, the National Council of Teachers of Mathematics (NCTM) Standards, Accreditation Board for Engineering and Technology (ABET) criteria;
- Provide exemplary strategies and tactics to bridge potential AP® (dual-enrollment) frameworks to existing academic year and informal programs;
- Quantify the demand for a AP® in Engineering and / or Engineering Design Program; and
- Suggest a professional development process to prepare teachers on Engineering and Design instruction.

To date, these goals have been addressed roughly in three phases – with Phase III ongoing:

- Phase I: Initial study and report to the College Board and National Science Foundation, covering the period from February 2005 until November of 2007.

- Phase II: Development of the draft Design Process Rubric leading up to the Engineering Design Process Portfolio Scoring Rubric (EDPPSR), covering the period from 2007 until the fall of 2010.
- Phase III: Development of a strategy and plan to validate and determine the reliability of the EDPPSR, covering the period from the fall of 2010 to the present time.

Phase I: This study has been conducted under a series of Institutional Review Board (IRB) approved protocols. During this phase, there have been formal meetings, interviews, opinions and beliefs expressed by institutions, associations and individuals. These activities have been conducted in context of focus groups, expert interviews, presentations, reports, workshops and a retreat. The participants have included:

- Middle school teachers.
- High school teachers, curriculum advisors and administrators.
- University faculty representing the sciences, technology, engineering, education and mathematics.
- Educators representing organizations, such as the American Association for the Advancement of Science and Oak Ridge Associated Universities, and the Teaching Institute for Excellence in STEM.
- Members of engineering associations such as the American Society of Mechanical Engineers, the American Society of Civil Engineers, the International Technology Education Association, the Engineering Society of Baltimore, Engineering Founders Society and the American Society of Heating, Refrigerating and Air Conditioning Engineers.

In addition:

- Organizations, such as, the Center for Engineering Education and Outreach (Tufts), MESA Maryland, Society of Women Engineers, the Extraordinary Women Project (American Society of Civil Engineers), and Achieve have provided individual or organizational inputs.
- Other organizations such as the College Board, the National Science Foundation, and the Kern Family Foundation have been provided reports.
- Policy makers, such as from the House Committee on Science and Technology have been advised as to the findings.
- Engineering education programs such as the Center to Advance the Teaching and Technology of Science, the Infinity Project, National Center for Technology Literacy, and Project Lead the Way have been consulted, and / or have had individuals participate.
- Community colleges, such as Howard Community College have been engaged.

- Specialized organizations, such as the Maryland Center for Career and Technology Education Studies and the Communities Foundation of Texas have been consulted.
- Industry has provided both support and participants.

Overall, 10 focus groups were convened with a total of 104 participants at: Carnegie Mellon University; California State University at LA; the International Technology Education Association annual meeting; NEES Consortium, Inc.; North Dakota State University; Tufts University; Vanderbilt University (twice); and Southern Methodist University. In addition, over 20 experts were interviewed telephonically. In addition, a pilot to study the possible delivery and impact of an Introductory Engineering course was offered to 165 students high school students during the summer of 2006. The pilot was based on the Johns Hopkins University course, *What is Engineering*? A retreat was held in November of 2006 at Carnegie Mellon University to review and comment on the results to date with over 20 attendees. A report was issued in April 23, 2007 to the College Board and the National Science Foundation, entitled, *Pre-Advanced Placement Plan*. [33] The College Board issued an opinion in 2007.

Phase II: Continuing an approved Institutional Review Board process, teachers, community college and university faculty worked to develop an initial rubric for the design process through funding provided by a NSF SITE Research Experiences at the University of Maryland, at College Park (UMCP) and the University of Virginia (UVA). The initial rubric was developed during the summer of 2008, and was reformatted in consultation with staff members from the Kern Family Foundation. Again under an approved IRB process, this initial Design Process Rubric was reviewed, critiqued and revised by a focus group supported by the Kern Family Foundation in March of 2009 held on the UMCP campus. The focus group included 30 individuals from institutions who had previously participated in Phase I, and several new organizations, including the Department of Defense, Olin College, Oklahoma State University, RIT, US Military Academy, the US Naval Academy, University of Notre Dame, industry and several high schools in Illinois, Oklahoma and Texas. The results of this two-day session were reviewed, and the Design Process Rubric was modified. A team of SITE RET teachers, a community college faculty member and university faculty then reviewed the modified Rubric to compare to existing design process models and rubrics during the summer of 2010. In the fall of 2010, two performance-based experts were engaged to review, critique and suggest modifications to the initial Design Process Rubric. Based on the recommendations of these consultants, the Rubric was modified, reformatted, and retitled as the *Engineering Design Process Portfolio Scoring Rubric* (EDPPSR).

Phase III: This phase is the ongoing develop of a strategy and implementation of a plan to determine the reliability and the validity of the EDPPSR model. The intent of the EDPPSR is to eventually offer a validated and reliable framework for a performance-based assessment of the engineering design process of use to educators, teachers, faculty, students, admission officers and program sponsors. The ultimate goal of the EDPPSR is to provide a means by which to evaluate and score a student's participation in an engineering-based project, regardless of the setting – e.g., formal (classroom, curriculum-based) versus informal (extra-curricular). Too often, students participate in programs that include extensive project-based activities (in both formal and informal settings) in which the knowledge and skills learned are not effectively scored or rated for the purpose of: (1) admissions into other project-based programs; (2) admissions into post-

secondary studies; (3) career pathway recognition; and (4) advanced Placement or dual-credit into more rigorous academic courses. Initial funding is being provided in 2011 by the Kern Family Foundation for a scoring study that will allow the initial testing of the EDPPSR model through the development and evaluation of a scoring protocol to be followed by raters convened at the UMD to review the contents of sample Portfolios submitted through the newly launched Project Lead the Way Innovation Portal.

Results

In order to organize the reporting on the various activities and outcomes over the past five years, the results will be summarized in context of the Phases I, II, and III.

Phase I:

The following is a synopsis of the findings from the focus group sessions:

- Advance Preparation is as important as Advance Placement® for student success in the first year of their engineering studies – in fact, a common consensus was that the preparation in science and mathematics content and skills was far more important than the placement into more advanced undergraduate engineering courses.
- The content of a pre-college course should inspire and inform students about:
    - Definitions of engineering (What is engineering?)
    - The various disciplines in engineering
    - The design process
    - How things work
    - The application of STEM concepts and skills
    - Problem solving
    - Communication and writing
    - Presentation skills
    - Group work
- Higher education faculty considered AP® credit as problematic, a number of focus group interviewees and the experts indicated that the AP® Engineering credit would not be accepted for an introductory engineering course.
- Open questions for an AP® Engineering Course were:
    - Should all engineering fields be represented if only one course is the option?
    - What design and problem solving concepts should serve as anchors for the course?
    - Should a digital portfolio and other assessment tools be used to record and capture a student's full range of engineering based activities?
    - How should teachers, practicing engineers, professors, undergraduates, guidance counselors be included in the design of the AP® (or dual-enrollment) course of study?
    - How do we integrate the multiple learning and practice options for students with regard to engineering concepts – e.g. formal and informal?
    - Should we consider teaming the teachers with other content experts?

The following is a synopsis of the findings from the expert interviews that engaged over 20 individuals with expertise as teachers, faculty, administrators and educators:

A common consensus was that the secondary school engineering program should better prepare students to succeed their first year in engineering. There was also recognition that the electronic portfolio concept would provide a "different" academic perspective of a student, and if submitted with their transcripts might give a student an "edge" in the admissions process. Finally, three potential pathways existed: (1) one that better prepared students in mathematics and science; (2) one that could lead to actual AP® credit; and (3) one that allowed the student to earn dual-enrollment credit at the secondary and undergraduate level.

Finally, higher education might accept an "AP® credit" in engineering under several conditions: (1) in lieu of an introductory engineering course; (2) as a science elective; (3) as a general elective; or (4) not at all. AP® Calculus was the most often cited model.

The following is a synopsis of the most common course characteristics of the 35 Introduction to Engineering syllabus that were reviewed found that the learning objectives included:

- Design process
- Problem solving
- Creative thinking
- Teaming
- Technical and Engineering communications
- Ethics
- Basic computer tools
- Time management
- Project management
- Modeling
- Graphics
- Apply mathematics and science knowledge
- What it means to be an engineer
- Role in society

The following is a synopsis of a pilot of a secondary-level Introduction to Engineering Course:

- Model: The pilot was that offered during the summer program of 2006 was modeled after the Johns Hopkins University (JHU), *What is Engineering?* The course was team taught by JHU approved instructors who were required to take a one-week training course. As teaching assistants, high school teachers, undergraduates and graduate students provided tutorial support. The JHU faculty administered the final grades, with students' that received an A or B earning a JHU transcript.
- Sections of the course were offered at the:
  - Johns Hopkins University - Homewood Campus - two sections.
  - Johns Hopkins University - Montgomery Campus - one Section.
  - Mathematics Science Technology Charter School, Washington DC (MSTCS) - one Section.
  - Mathematics Engineering Science Achievement (MESA) - four Sections.
  - Upward Bound (Cal Lutheran) - one Section.
- Demographics and Results:

    - 200 students Applied; 165 were Accepted; and 154 Completed the Course.
    - 19 received A's, 62 B's (52% received 3 JHU credits); 71 received JHU Certificates of Completion; and 2 received a Certificate of Attendance.
    - 49% were female; 60% identified themselves, as African American, Latino, Asian American or Native American.
    - 83% received financial aid – full scholarship.
  - Financial sponsors included: NSF, MESA, industry, individuals, JHU and Foundations.

The following is a synopsis of the recommendations of the Carnegie Mellon University retreat:

- We should think more broadly about the faculty and inclusion of teachers of who will teach the class – team teaching to provide professional development for both faculty and high school teachers.
- Design the AP® assessment process to address what is known about best practices in engineering education – take into consideration ABET criteria and aligning to the AP® curriculum.
- Perhaps an AP® in STEM should be considered as an alternative or as a complement.
- Consider an AP® in Engineering for each discipline of engineering (i.e. biomedical civil, electrical, mechanical, etc.), however a course that provides a solid sampling would be acceptable.
- It is important to note that "systems thinking" is an important aspect along with the design process.
- Important questions that need to be addressed are: Why am I teaching these concepts? Where will they be used? How can the same math be applied to different fields within engineering?
- Teachers should be STEM certified – Chemistry, Physics, Biology, and Calculus.
- Encourage individuals who are studying engineering to become teachers.
- Use major STEM concepts and show how they are connected and applied to various areas of science and engineering - i.e. the concept of flow used in electricity, liquids, etc.
- Alternative certification routes for professionals and others who choose to teach the AP® Engineering course.
- Identify relevant policy issues, e.g., NCLB, 4-By-4 Math and Science, etc., and how they impact AP® Engineering.

Phase II: This phase progressively explored the development of a Rubric for the Design Process involving teachers, community and higher education faculty, and experts in performance-based assessment. A focus group was held at the UMCP campus in March of 2009 to review the initial Design Rubric model that has been modified by consultants into the present Engineering Design Process Portfolio Scoring Rubric (EDPPSR) model as shown in Inserts 1 and 2. This current model provides evaluative criteria for the various elements of each of seven EDPPSR components or steps identified in the design process: 1) identifying, articulating, and justifying a problem; 2) analysis of current and past solution attempts; 3) generating an original solution; 4) constructing a testable prototype or process; 5) analyzing test data; 6) reflecting and formulating recommendations; and 7) documenting and presenting the project. Each component is comprised of one or more elements or traits for which sub-scales and descriptors for each of six levels of performance were developed based on a generic scoring scale presented in Insert 2.

Insert 1: EDPPSR Generic Scoring Scale and Descriptors

The Engineering Design Process Portfolio Scoring Rubric EDPPSR identifies six levels of performance based on the following generic scoring scale:
5 Exemplary: Demonstrates thorough and penetrating understanding of key concepts; exhibits copious evidence of attainment of skills
4 Advanced: Demonstrates considerable understanding; exhibits considerable (substantial) evidence of attainment of skills
3 Proficient: Demonstrates general /adequate understanding of key concepts; exhibits adequate evidence of attainment of skills
2 Developing: Demonstrates a partial understanding of key concepts; exhibits some evidence of attainment of skills
1 Novice: Demonstrates a lack of/little understanding of key concepts; exhibits minimal evidence of attainment of skills
0 No evidence (No evidence of engagement, pre-engagement**)**: Demonstrates no understanding of key concepts; exhibits no evidence of attainment of skills

The relationship between the generic scale and the performance levels and specific performance criteria for each of the EDPPRS elements is demonstrated in Insert 2, which includes examples of two of four element subscales and descriptors for the Component 1 (Identifying, articulating, and justifying a problem).

Insert 2: Examples of Component Element Score Scales and Descriptors

Component 1, Element A: Identification and Definition of the Problem:
Score of 5: The problem is clearly and objectively identified and defined with considerable depth and consistent precision of detail as elaboration.
Score of 4: The problem is clearly and objectively identified and defined with some depth and precision of detail as elaboration.
Score of 3: The problem is clearly and objectively identified and defined with adequate depth; some detail may be imprecise (general) or unelaborated.
Score of 2: The problem is identified and defined in a manner that is sometimes/somewhat unclear and/or may manifest some subjectivity.
Score of 1: The identification and/or definition of the problem is unclear and/or is clearly subjective
Score of 0: The identification and/or definition of the problem is missing OR cannot be inferred from information included.

Component 1, Element B. Justification of the Problem:
Score of 5: The justification addresses all angles or aspects of the problem (producer, distributor, consumer, end-user) and is based on comprehensive, timely, and consistently credible sources; it offers consistently objective detail from which goals and measurable design parameters can be determined.
Score of 4: The justification addresses many but not all angles or aspects of the problem and is based on a variety of timely and generally credible sources; it offers objective detail from which goals and measurable design parameters can be determined.
Score of 3: The justification addresses several angles or aspects of the problem and is based on several generally timely and credible sources; although not all information may be objective, it

offers enough objective detail from which goals and design parameters can be determined.
Score of 2: The justification addresses only one angle or aspect of the problem and may be based on insufficient sources and/or some sources that are outdated or of dubious credibility; at least one objective goal or design parameter is derived from sources presented.
Score of 1: A justification, if intended, is not clearly linked to any angle or aspect of the problem and/or is based on sources that are overly general, outdated, and/or of dubious credibility; general design parameters may be presented but the information provided does not allow for the determination of objective or measurable goals.
Score of 0: A justification of the problem is missing, cannot be inferred from information included as evidence, or is essentially the opinion of the researcher.

The EDPPSR is designed to apply to any portfolio that is intended to document an individual or team-driven process leading to an original attempt to design a product, process, or method to provide the best and most optimal solution to a genuine and meaningful problem. In essence, the portfolio should be a detailed account or "biography" of a project and the thought processes that inform that project. Besides narrative and explanatory text, entries may include (but need not be limited to) drawings, schematics, photographs, notebook and journal entries, transcripts or summaries of conversations and interviews, and audio/video recordings. Such entries are likely to be necessary in order to convey accurately and completely the complex thought processes behind the planning, implementation, and self-evaluation of the project.

The portfolio should capture the mathematics and science principles used to predict outcomes throughout the design process. Trial and error demonstrations are not rigorous enough to show mastery of fundamental concepts central to engineering design. In addition, the portfolio should document the following three overarching facets of the design process: reflection, iteration, and articulation of limitations:

1. **Reflection**: A well-documented design process conveys the thinking that informs each step, and explains the bases for observations, interpretations, actions and decisions. Reflection is essential to the continuous improvement that should be realized through the design process itself.

2. **Iteration**: The nature of engineering design is that all of the answers are not known before the design process begins, but rather, that new ideas or lessons learned will emerge during that process that impact subsequent actions or would do so were time or resource constraints not an impediment. The iterative process is recursive rather than linear, and often involves going back to review and revise earlier thinking in order to move forward.

3. **Articulation of limitations**: Engineering design often requires years of iterative research, development, and testing, with access to, and consumption of, abundant resources. In the absence of adequate time or human and material resources, students should identify and explain the resultant impact on their design and discuss what could be done additionally to justify the viability of their design and ideas. The inclusion of supporting detail, such as the recommendations of experts, in similar contexts will enhance the validity of the students' articulation of limitations and the means of addressing those that the students propose and justify.

Phase III: The EDPPSR model as currently rendered has a strong theoretical foundation as it has been developed by reference to the literature on the steps of the design process, through focus groups supported by NSF and Kern Family Foundation funding, and through expert review by teachers, faculty and researchers in performance based, portfolio rubrics and assessments. However, to date, there is no empirical evidence that supports the use of the EDPPSR model to evaluate student design-based projects in a reliable and valid manner. In order to demonstrate the reliability and validity of the EDPPSR model a plan has been developed to:

- Align the rubric sub-scales and descriptors with exemplar artifacts representative of the design process across formal and informal settings, education grade levels, and programs;
- Demonstrate that the EDPPSR can produce reliable scores within and across diverse raters;
- Establish theory consistent relationships between EDPPSR scores and relevant engineering outcome scores; and
- Determine whether the model in its entirety or in part adequately describes the engineering design process.

Through initial funding provided by the Kern Family Foundation, implementation of the plan will begin with a 2011 study that will involve a team of 7 - 8 engineering content experts (including instructors at both high school and college level and extracurricular project mentors directly involved in programs with a portfolio component) who will be led by assessment specialists, through a series of activities that will include – although may not be limited to – the following:

- Round-robin independent scoring by team members of a small subset of portfolios (in both electronic and hard copy format) with documentation of score decisions substantiated by reference to the language of the rubric and the decision-making process.
- Documentation of questions and concerns during independent scoring, to provide a record of such potential problems as cognitive dissonance (e.g., a "gut-level" concern about the accuracy or appropriateness of a score decision assigned by a reviewer on the basis of words/phrases in a given rubric--that is, instances in which the scoring criteria themselves led to a judgment that the reviewer felt was too high or too low); redundancies (instances in which reviewer feels "I've already looked at and made a score decision based on those criteria"); omissions (reviewers' perceptions that key evidence of thinking/learning was not addressed or "given credit"); and instances of ambiguous or inaccurate language.
- Discussion of score decisions leading to selection of provisional anchors upon which consensus has been reached (examples of work illustrative of particular score points for each rubric element).
- Double-scoring of additional portfolios by spiraled reader pairs to obtain preliminary inter-rater reliability data.
- Assignment of holistic score for each portfolio by team members other than reader pair and comparison of holistic and analytic scores.
- Comparison of holistic scores by team members and outside experts to confirm “true scores” for training purposes.

Summary

The nearly five year study has recognized the following challenges and barriers to students and their teachers engaging, pursuing and transitioning between secondary an undergraduate engineering studies: (1) deficiencies in existing assessments to measure a student's interdisciplinary skill and knowledge with regard to the practice of the steps within the engineering design process; (2) a lack of resources to offer an AP® course of study; (4) the multitude of formal and informal educational opportunities for students' to engage in design based activities; (3) classroom management issues in problem-based learning; (5) limited teacher and mentor professional knowledge in engineering content and non-routine problem solving; (6) the resistance to the acceptance of secondary student work as a pre-requisite for credit at the undergraduate level; (7) the lack of engineering-based education standards at either the secondary or undergraduate level; and (8) the challenge of incorporating new content into existing schedules, informal offerings, and experiences, within the high-stakes testing environment of No Child Left Behind.

The network of teachers, faculty, administrators, educators and researchers continue to be engaged in ongoing activities, such as the development, review and testing of the EDPPRS model.

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