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The Engineering Design Process Portfolio Scoring Rubric (EDPPSR) – Initial Validity and Reliability (Fundamental)

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Abstract

Research prior to 2005 found that no single framework existed that could capture the engineering design process fully or well and benchmark each element of the process to a commonly accepted set of referenced artifacts. Compounding the construction 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.

The Engineering Design Process Portfolio Scoring Rubric (EDPPSR) was 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 rubric is comprised of four main components, each in turn comprised of three elements. Each element has its own holistic rubric.

The process by which the EDPPSR was created gives evidence of the relevance and representativeness of the rubric and helps to establish validity. The EDPPSR model as originally 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 and through expert review by teachers, faculty and researchers in performance based, portfolio rubrics and assessments. Using the unified construct validity framework, the EDDPSR's validity was further established through expert reviewers (experts in engineering design) providing evidence supporting the content relevance and representativeness of the EDPPSR in representing the basic process of engineering design.

This manuscript offers empirical evidence that supports the use of the EDPPSR model to evaluate student design-based projects in a reliable and valid manner. Intra-class correlation coefficients (ICC) were calculated to determine the inter-rater reliability (IRR) of the rubric. Given the small sample size we also examined confidence intervals (95%) to provide a range of values in which the estimate of inter-reliability is likely contained.

Introduction

At the inception of this body of work in 2006 and largely still true today, 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" [1]. Archbald and Newmann [2] and Paulson, Paulson, and Meyer [1] 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 20,000 portfolios a year [3]. In reference to the Studio Art portfolio, Wolf, Bixby, Glenn, and Gardner (1991) [4] 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.

The intent of this work began with the development of a similar body of information regarding representative work and evaluative criteria for the engineering design process that is a basis to align student work across project-based opportunities [5,6]. Through such alignment, the potential exists for students' work to be recognized and appreciated as they progress in their academic and career aspirations. As documented in Goldberg's 2014 study [7], the Engineering Design Process Portfolio Scoring Rubric (EDPPSR) model, as rendered at this time point, has a strong theoretical foundation as it has been developed by reference to the literature on the steps of the design process through 15 focus groups and workshops including over 200 expert teachers, faculty and researchers in performance based, portfolio rubrics and assessments. Only limited empirical evidence to support the use of the EDPPSR model to evaluate student design-based projects in a reliable and valid manner has been published, to date [8]. In order to demonstrate the reliability and validity of the EDPPSR model it is essential 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
- Determine whether the model in its entirety or in part adequately describes the engineering design process.

The EDPPSR is designed to apply to any portfolio created most often by high school or college students 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:

- **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.
- **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.
- **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.

The rubric is comprised of four main components, each in turn comprised of three elements, as detailed in Figure 1. Each element is broken down into a series of sub-elements that are scored on a scale of 0 (no evidence), 1 (novice), 2 (developing), 3 (proficient), 4 (advanced), and 5 (exemplary). For example, Element A is "Presentation and Justification of the Problem" with rubric descriptors that address problem identification, problem definition, problem elaboration, justification of the problem based on stakeholder input, justification of the problem based on credible sources, what fraction of design requirements can be determined from the objective detail, and how measurable and detailed the design requirements are. The full rubric is available in Appendix A.

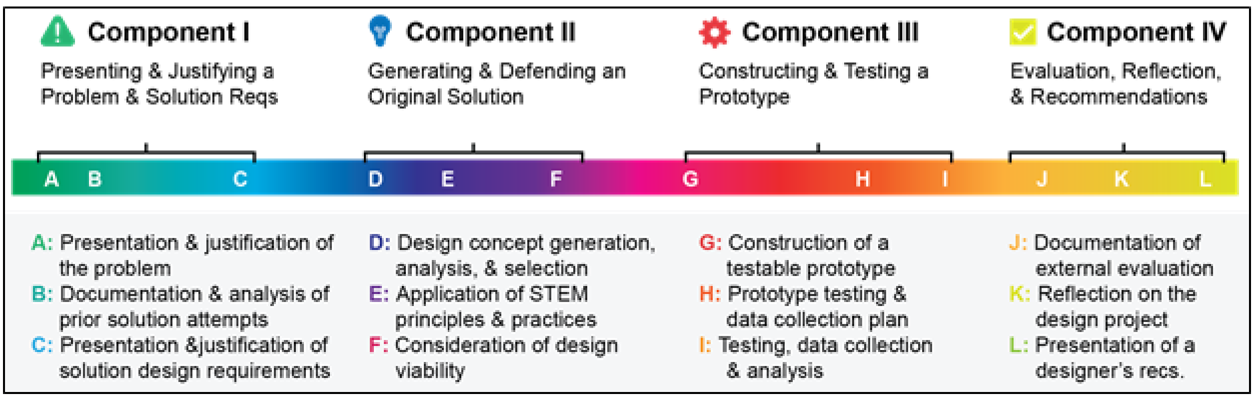

Figure 1: The EDPPSR is comprised of four components each made up of four elements, A through K. Each element contains a group of sub-elements that is then scored on a scale of 0-5.

Literature Review

Moskal and Leydens provide a helpful summation of the literature behind establishing a rubric's validity and reliability [9]. They write, "Validation is the process of accumulating evidence that supports the appropriateness of the inferences that are made of student responses for specified assessment uses. Validity refers to the degree to which the evidence supports that these interpretations are correct and that the manner in which the interpretations are used is appropriate." Evidence of validity is gathered through three primary types of evidence: content, construct, and criterion. Content-related evidence relates to the extent to which a student's response to an assessment measures how well they understand that topic. Construct-related evidence shows that an assessment "measures completely and only the intended construct." Criterion-related evidence "supports the extent to which the results of an assessment correlate with a current or future event."

Reliability simply refers to the consistency of an assessment's scores [9]. Inter-rater reliability is the degree to which different raters make the same score decisions when applying the same criteria—in this case, the EDPPSR. Scoring levels on a rubric should guide an evaluator to give the student response the same score.

The development of a bank of portfolio entries with exact agreement scores – termed anchor papers [9] or an anchor set – is a critical component of efforts to refine and validate the use of the Engineering Design Process Portfolio Scoring Rubric (EDPPSR). Such entries are needed as part of a scoring training protocol that must be developed before investigators can conduct formal scoring studies (e.g., studies of score validity and reliability). Anchor papers may be referred back to by a scorer to help anchor themselves when they are scoring new student work and need to make sure that their scores do not drift over time. These entries can also serve as illustrations of student work to inform teaching and learning. A training set of scored student work should also be created to allow new scorers to learn how to use the rubric.

Research Questions

The research questions for this study are the following:

- Can and how well does the EDPPSR produce reliable scores within and across diverse raters?
- Is the EDPPSR a valid instrument?

Methods

Given that EDPPSR research was in its infancy, we selected a mixed-methods approach. This combined quantitative and qualitative analytic strategy [10] is especially advantageous to test specific hypotheses regarding the EDPPSR (e.g., criterion-related validity evidence for EDPPSR scores) and gain a nuanced understanding of how experts and students apply the EDPPSR in diverse settings. Ultimately, this mixed-methods approach might provide a clearer understanding of the appropriateness and utility of the EDPPSR versus a single method strategy [11]. We will use quantitative methods including content analysis [12], correlation/regression analysis [13], and measure development best practices [14] to establish the reliability and validity of EDPPSR scores; we will use qualitative analysis [15] to elucidate ways in which experts, instructors, and students use the EDPPSR in design projects and in various engineering settings.

To begin to gather the necessary data, a scoring workshop was conducted in October 2013. The primary purpose of this workshop was to obtain examples of portfolio entries with exact agreement scores that could serve as illustrations of different score points for each element of the Engineering Design Process Portfolio Scoring Rubric (EDPPSR). These illustrations were intended for instructional and assessment purposes. In contrast, the purpose of the workshop held in January 2015 was to obtain sufficient data to make a preliminary determination of EDPPSR inter-rater reliability. The team was also interested in collecting score data to evaluate test-retest reliability (the stability of score decisions over time). It was also anticipated that the workshop would yield additional samples that may serve as examples of score points for which we did not yet have an illustration.

In order to provide clarity about the two workshops and their subsequent data analysis, this manuscript will present the procedure, participants, data, and analysis for each workshop *separately* and *subsequently*. The results from the October 2013 workshop are necessary to understand how the 2015 workshop was designed and conducted. To that end, the reader will find workshop sections of the paper labeled as either *2013* or *2015*.

Note: The Innovation Portal was a free service offered by Project Lead The Way (PLTW) for electronically submitting and managing engineering design process portfolios and scoring with the EDPPSR that allowed large scale data collection. This research utilized the tool to gather portfolios for research purposes. The portal was sunsetted by PLTW in June 2020 and no longer exists.

Participants – 2013

For the workgroup in 2013, the selected scorers fit one of three profiles: 1) four were recruited from among those engineering educators who participated in a previous scoring workshop; 2) three were chosen from among university-level faculty with interest in the EDPPSR but no prior experience with/exposure to any beyond the draft version of the rubric; and 3) four were selected from the pool of Project Lead the Way master teachers on the basis of their considerable familiarity with—and ongoing use of—the EDPPSR in high school classroom contexts.

Procedure – 2013

Preparation for the workshop - 2013

Twenty portfolios were identified from those posted within the previous year on the Innovation Portal for which permission to share the work for research purposes and public information had been granted. The portfolios were pre-screened to ensure that they were complete, and they were then redacted to remove any personal or identifying information (e.g., students and teachers' names, photographic images of faces, school information, etc.).

The workgroup leader conducted prescreening of the available portfolios. The purposes of this prescreening included but were not limited to selection of two portfolios that would be the focus of whole-group scoring exercises and would later provide the "true scores" against which pre- and post-workshop scores by participants at a rubric orientation workshop would be compared. The wide difference in participants' experience called for the design of a scoring and rater pairing plan that would take advantage of the expertise that existed within the team and maximize the opportunity for those without any prior experience or even exposure to scoring with the EDPPSR to develop understanding of the scoring process and the evaluative criteria set forth in the rubric. Score record sheets were designed to capture any patterns of performance that might be associated with differences in rater background and experience.

Conduct of the Scoring Workshop - 2013

The workgroup leader established the two-fold purpose of the workgroup: 1) to obtain consensus scores on two full portfolios to be used first for research purposes, and eventually shared for instructional purposes; and 2) to obtain exact agreement scores on entries that can be used for instructional and assessment purposes as examples of various score points, with the goal of completing a full *anchor set* (an exemplar for every score point for Elements A-L of the rubric) and beginning to compile one or more *training sets*.

Participants were provided with a brief overview on scoring with the EDPPSR. The limited time available precluded a more in-depth training for those new to the rubric, but it was hoped that through the whole-group activities all participants would improve scoring accuracy and confidence applying the rubric. The brief overview addressed methodology (modified holistic scoring) and uses of various resources including annotated scored entries and portfolios.

Following the overview, participants were led through a whole-group scoring exercise. Every rater was provided a copy of the EDPPSR, a packet with the highest-scoring sample entry for each rubric element currently posted on the Innovation Portal, and a copy of Portfolio A ("Multi-Size Screwdriver"). Initially focusing on a single element at a time, raters were instructed to score the entry for that element independently, recording their score decision and documenting it with brief notes. Once all workgroup members had completed these steps, discussion of the scores ensued. Care was taken to hear rationales for all score decisions, but with greater attention paid to those score points assigned by the majority of the raters to close in on the most defensible score. Barring clear consensus, the group was guided to at least reach agreement on the "score line" or pair of adjacent score points most defensible. See Table 1 for consensus scores for Portfolio A. Scores adjacent to any of the single scores or either of the scores represented in the split scores would be deemed to match these provisional "true scores."

Table 1: Consensus Scores on "Multi-Size Screwdriver"

Element	A	B	C	D	E	F	G	H	I	J	K	L
Score	2-	3-	1/2	1/2	0/1	0/1	0/1	1	1	0/1	2/3	2

The second whole-group exercise followed much the same process, except that raters were asked to score Portfolio B ("Crutch Beverage Holder") independently and fully before discussion of original score decisions took place, element by element. Once again, participants were encouraged to explain the rationale for original score decisions and then listen and respond to different judgments by others. All raters had the opportunity to confirm or change their original score on the basis of insights/observations shared during the discussion of each element entry. In a few instances, where there was difficulty reaching consensus, the scoring lead decided to delay assigning a "true score" with the intent of revisiting discussion the following day after raters had a bit more scoring experience and discussion could also be informed by one experienced rater who was unavailable for part of the Portfolio B discussion (and indeed did not complete scoring of that portfolio). See Table 2 for the consensus scores reached following all discussion.

Table 2: Consensus Scores on "Crutch Beverage Holder"

Element	A	B	C	D	E	F	G	H	I	J	K	L
Score	3/4	3	4	4	2	2/3	4-	2/3	3/4	3	1	2/3

For the next phase of the scoring workgroup, new, never-before scored portfolios were distributed to raters for paired, independent readings. Assignments were made to ensure that rater pairs always included two of the three rater profiles (experienced raters, inexperienced university-level raters, and raters with classroom experience using the EDPPSR). For the initial individual assignments, portfolios were selected that were most likely "mid-level" in quality based on the scoring lead's preview. This was intended to provide a foundation before turning to some stronger and weaker portfolios. The first independent scoring was assigned as homework between sessions. Once both independent readings for each distributed portfolio were completed and analyzed for discrepant scores requiring adjudication by a third rater, new and as-yet unscored portfolios were distributed, along with portfolios with required third readings flagged.

The scoring lead guided the group's attention to several of the entries in the second research portfolio—Portfolio B ("Crutch Beverage Holder"). Based on further discussion, a few needed consensus scores were determined. Raters were asked to document the length of time it took them to score each portfolio. On average it takes 50 to 70 minutes to read, score, and provide brief notes to explain each score decision. It can be anticipated that without having to annotate score decisions (e.g., for purposes of scoring for placement and/or scholarship decisions), this time would be reduced by at least 10-15 minutes.

Paired raters continued to complete independent readings, with third-rater scores being generated as needed to resolve discrepancies. However, in anticipation of very high scores on one portfolio, the scoring leader assigned that portfolio to three, rather than only two, raters for independent scoring. When all three had completed scoring of that portfolio, "Forklift Safety," the lead flagged all those entries that received a score of 5 from at least one of the three raters. Individual work was halted so that the portfolio could be shared online with all workgroup participants, who could then weigh in after score rationales were presented by the three raters originally assigned this portfolio.

At the time when this group discussion was conducted, it was anticipated that the results would merely inform selection of training samples at the high end of the score scale. Due to a technical problem distributing the research portfolio intended to be scored by post-workshop by attendees of the scoring orientation workshop, the decision was made to substitute "Forklift Safety" for that portfolio. Therefore, consensus scores based on at least three independent raters' scores, along with group input in some instances, wound up being extremely valuable as the study could proceed. See Table 3 for scores for this portfolio.

Table 3: Consensus Scores on "Forklift Safety"

Element	A	B	C	D	E	F	G	H	I	J	K	L
Score	4/5	4/5	5-	3/4	5	4/5	4/5	3/4*	3**	3/4	4/5	3/4

* Discrepancy among 3 raters (1, 3 and 4 assigned)

** Discrepancy among 3 raters (2, 3 and 3/4 assigned)

Scoring then continued independently. Individual record sheets were compared and third rating sheets were prepared for all discrepant scores. By the end, all portfolios had received two independent scores, and nearly all received third readings when required. The results of independent ratings appear in Appendix B. The progress towards building an anchor set is shown in Appendix C.

Results – 2013

Reliability

From the eighteen portfolios that were scored independently in 2013 by two or more raters, 48 of 216 scores (22%) were discrepant as can be seen in Appendix B. Of those, the third rater agreed with one of the two previous scores 11 times. This compares favorably to 31% discrepant scores during independent scoring in 2011 but unfavorably to 11.5% discrepant scores in 2012. This drop in performance from the previous scoring workgroup may be attributed at least in part to the lack of familiarity of some raters to the EDPPSR and Innovation Portal resources (supported by the observation that two of these raters tended to score higher or lower than the other raters with whom they were randomly paired). These raters also scored more rapidly than the experienced raters (those who had participated in past scoring workgroups and the master teachers who have been using the EDPPSR), and one may surmise that there was some sacrifice of accuracy to speed. It was anticipated that monitoring during the inter-rater reliability study in 2015 would allow the team to learn more about appropriate pacing to ensure higher accuracy.

Participants – 2015

In 2015, workshop participants were recruited from the pool of high school and college educators who had previously participated in at least one EDPPSR scoring workshop. Each invitee had to commit to participating for the full duration of the workshop and to completing beforehand a training set comprised of sample previously scored portfolio entries that would be made available to them electronically. The exception was one participant who had never participated in a previous scoring workshop but who had attended a workshop to introduce the EDPPSR and had experience using the EDPPSR to score student portfolios. Given the uncertainty that all ten participants would be available, an eleventh participant was invited. The plan, should all of the original ten participants attend (which in fact turned out to be the case), was to have the eleventh "shadow" the participant whose training set scores most often fell outside (and by a wider margin) the intended "true" scores for those entries.

Procedure – 2015

Preparation for the workshop - 2015

Thirty new portfolios were initially identified from those posted on the Innovation Portal since the previous scoring workshop for which the students involved had granted permission to share the work for research purposes and as public information. Having ascertained that 40-45 portfolios were needed to obtain sufficient score data to inform preliminary judgments about inter-rater reliability, the pool of portfolios was supplemented with fifteen portfolios that had been previously scored during the October 2013 workshop. The inclusion of these previously scored portfolios was also intended to provide the means of determining test-retest reliability. Portfolios were obtained from a variety of sources including high school students (mostly from Project Lead The Way (PLTW) and some from an extracurricular summer program), university students, high school teacher teams during professional development, and active military. The variety of sources provided evidence of the applicability of the EDPPSR to portfolios from diverse sources/instructional contexts. Of the 2013 portfolios, students had created thirteen, and teachers, three. The new portfolios came from the following sources:

- 14 portfolios from high school students (12 PLTW; 2 from extracurricular summer program)
- 7 portfolios from university students (3 underclassmen and 4 seniors)
- 5 portfolios from high school teacher teams (PLTW summer training)
- 3 portfolios from active military

The new portfolios were pre-screened and they were then redacted to remove any personal identifying information (e.g., students' and teachers' names, school information). Any photographic images of the designers included in the portfolios were left intact since identifying information had been removed. All redacted portfolios were organized in a folder on the Innovation Portal to which only the workshop participants would have electronic access.

Every portfolio was to be scored independently by two raters, and then given to a third rater when it was necessary to resolve discrepant scores. In order to obtain inter-rater reliability data, portfolios were assigned such that every rater was "paired" once with each of the others. With 45 portfolios and ten team members (the eleventh shadowing), this meant that each rater would score nine portfolios.

The assignment matrix was designed to meet the following conditions in addition to the requirement that every rater score independently a portfolio scored as well by each of the other team members:

- Assignments needed to include a mix of both new (never before scored) and old (2013) portfolios;
- No rater who had scored an old portfolio would be assigned the same portfolio to score in 2015;
- Each rater would score a mix of high school and college portfolios;
- No rater would score more than one portfolio from the same class/instructor;
- No rater would score his/her own students' portfolios; and
- Insofar as possible, the total pages to be scored would be comparable, so that no rater scored far more or far less than any other.

Participants were asked to complete scoring of one of the two training sets constructed for the 2015 workshop ahead of time.

The *training sets* created for the 2015 workshop were comprised of twelve sample entries, one for each rubric element (A-L). These sample entries were selected based on their having received exact agreement scores from two or more raters during the most recent (2013) scoring workshop. Scores for each entry ranged from 0 to 4. The training set was temporarily posted on the Innovation Portal, from which meeting participants could also access the rubric and anchor samples illustrating most—although not all—score points for each element.

All participants were sent a detailed email explaining how to access all necessary resources on the Innovation Portal in order to score Training Set #1. A score sheet was provided which, when completed, was to be returned to the workshop leader. All score sheets were received prior to the workshop, allowing for the preparation of notes used to guide discussion based on the initial score decisions of all participants. These notes included details on the past scoring history of training set entries, the score distribution among workshop participants, and issues and observations drawn from their score rationales.

Conduct of the Scoring Workshop

Training

The 2015 workshop began with Training Set #1, with the sample Element A entry. The tentative training score was identified and its origins explained (e.g., scores from one or more raters, one or both of whom were sometimes in attendance at the 2015 workshop). The workshop lead then shared a draft annotation for the tentative score. Also shared were one or more rationales provided by workshop participants when they submitted their scores; these were selected ahead of time and were chosen in order to highlight the basis for different score decisions. Participants were given the opportunity to review the training set entry and were led in discussion of the scores—both tentative training score and, in those instances when the majority of participants had an assigned a different score, their rationales for that score. In nearly all instances, a training score was confirmed by consensus (See Appendix D for original and revised scores for Training Set #1). Participants had been given a copy of their original score sheet (with their scores and rationales) upon which they could take discussion notes and were advised to refer to these examples, as well as the anchor examples posted on the Innovation Portal, when engaged in independent scoring later on during the workshop.

It should be noted that the training protocol followed prior to independent scoring during the 2015 workshop departed in some ways from a typical operational scoring training experience. Unlike the latter, scores were still "negotiable," and in fact some changes to provisional scores were made.

After discussion of Training Set #1 was done, participants scored Training Set #2 and the results were tallied, followed by discussion conducted much as it had been for Training Set #1. A key difference was that since rationales were not available for screening and selection for discussion ahead of time, selected participants were instead asked to share their rationales when scores differed. Discussion of Training Set #2 resulted in several changes in the provisional training score. See Appendix E for original and revised scores for Training Set #2. Participants were allowed to retain their individual score sheets as a reference during independent scoring (but these were collected at the end of the workshop in order to consult score rationales when refining annotations for later use).

Independent Scoring

Participants were given a handout with instructions in the bulleted list below on engaging in this process. Each was given a slip of paper with his/her personalized scoring assignment. All scores were to be recorded on a hard-copy score sheet to make it easier to keep track of completed pairs and the need for third readings.

In contrast to past workshops, the 2015 score sheet included three columns. In addition to a Score column and another column in which participants were instructed to enter a brief Score Rationale based on features of the response and its comparison to the anchor and training set entries, the form included a third column labeled "Evidence in Other Element Entries." Participants were informed that they might wind up entering information in this column only infrequently, but that it was intended to allow them to note when students included information details in an entry for one element that—if placed or referred to elsewhere—would have improved that Element score. They were also informed that among the portfolios selected for scoring during the workshop are a few that are incomplete—usually because based on the duration of a course or program, students did not have the time to address all elements of the engineering design process. Rather than marking blank entries as "0," participants were asked to record a B (blank) for that missing entry (although some indicated a missing entry by putting an X in that cell). If they found that there is detail that would have contributed to a score for that missing entry, they were to use the third column to note where (under which other Element entry or entries) that detail appeared.

Participants were also informed that in a few instances they would find that supporting material in a portfolio is missing—most often these were photographs to which the students' text refers (due to broken links). They were instructed to go ahead and assign a score for an entry missing supporting material to which it refers, but to put an asterisk next to the score and in the rationale identify what is mentioned but is missing.

Participants were reminded that there is no single right way to score portfolio entries, but were given the following recommended procedure:

- Open the portfolio and proceed with one rubric element at a time, beginning with Element A. Read the EDPPSR score point descriptors for Element A. If you are already sufficiently familiar with the rubric that you can rule out some of the score levels, you may wish to focus in on a range of scores that at first glance seem possible for the training set entry for Element A.
- Refer back to the available anchors for Element A and the examples in Training Sets #1 and #2 and think about how the portfolio entry compares. Does it seem stronger than the score point 2 anchor, for example, and very similar to the score point 3 anchor?
- With a tentative score in mind, go back and reread the portfolio entry for Element A. Consult the EDPPSR score point descriptors for Element A again, to see which descriptor is the "best fit" with the training set entry. Remember that not all descriptors for any given score point must apply in order to assign that score. Rather, you should ask yourself, "Is this entry more like a 2 than a 1? Is it more like a 2 than a 3?" Decide upon and enter the score that fits best. If you are vacillating between two score points, by all means indicate this by adding a + or – OR by using a slash mark (e.g., 2/3). However, if you use slash marks, you MUST commit to one score (and can do so by circling the score upon which you settle). Once you have scored the portfolio entry for Element A, repeat the process for Element B, and so on through Element L.
- Please note that some raters prefer reviewing each Element rubric and associated anchors first, before looking at the new entry to be scored. You should feel free to determine the order of operations that works best for you, as long as you use the language of the EDPPSR and the available anchors to determine what score you think is most accurate for each entry in the training set.

- You should feel free to go back and look at a previously scored portfolio if consulting particular entries would help you make the most defensible decision when scoring another portfolio.

By the end of Day Two of the workshop some pairs were complete (had been scored independently by two raters) and the process of identifying needed third readings began (although no third readings were distributed until the first of the participants completed his/her original assignment).

While independent scoring was underway, the workshop lead was able to further review training set data and identify a few elements (E, G, K and L) that appeared to be more challenging than others. Particularly since participants had seen few entries at the high end of the score scale, prior to the beginning of Day Three a strong example of all but one of these elements was selected for use as a "*recalibration*" sample. The recalibration process usually involves the introduction of additional training materials to make sure that raters are "on target." Sometimes such materials are used to firm up raters' understanding of a particular score point on the rubric. The entries discussed were: Element E from Portfolio 02—Lawn Mower Kick Starter; Element G from Portfolio 15—Auto Visor Project; and Elements K and L from Portfolio 024—Forklift Safety.

Once discussion of these entries was concluded, participants resumed independent scoring. Only once more, during Day Three, was independent activity interrupted in order to share insights about scoring Element H (which was problematic sometimes for some raters). In each of these instances when particular elements were discussed in more detail, notes were taken that can inform any revision to the EDPPSR that takes place beyond this study.

By day's end, only a few scoring assignments had not been completed, and fewer than a dozen third readings were still needed. Arrangements were made for the completion of this work off-site shortly after the conclusion of the workshop, with all data to be returned to the workshop lead.

Results – 2015

The raw data were organized in order to proceed with selection of additional anchors to complete the anchor set posted online on the Innovation Portal and identification of additional entries with exact agreement that could be made available for instructional and assessment purposes (such as creation of additional training materials, revision/refinement of existing training sets, etc.). An overview of entries with exact, adjacent, and discrepant scores is provided in Appendix F. Appendix G reflects the updated Anchor Set.

Because score reliability is critical in developing sound research conclusions [16], we examined estimates of inter-rater reliability for EDPPSR rubric element scores (A through L) based on the intra-class coefficient. Raters were assigned portfolios to score based on a spiraling plan that paired each rater once with the ten others. Because the same raters did not score each portfolio, we ran a one-way random effects model (which treats variability due to specific raters, interactions of raters with persons/portfolios, and measurement error as error) for the intra-class correlation coefficient (ICC), which produces the most conservative (i.e., smallest) ICC value. Given the small sample size we also examined confidence intervals (95%) to provide a range of values in which the estimate of inter-reliability is likely contained.

As shown in Table 4, observed ICC values ranged from 0.338 (Element A) to 0.873 (Element B) and 95% confidence suggests that the range of scores could be as high as 0.655 (95% upper confidence interval for Element A) to 0.933 (95% upper confidence interval for Element B). These results suggest that raters generally produced reliable EDPPSR element scores (i.e., consistent scores which were not unduly impacted by measurement error). Although convention dictates that score reliability should be 0.80 or higher [17], given the small sample size and reduced score variability, our present findings are quite promising. Arter's criteria [18], identifies a "ready to roll" rubric as one for which "rater agreement rates are at least 65 percent exact agreement and 98% within one point" which lends a more favorable eye to these results. However, it is worth noting that two ICC values (for elements A and H) were low. Although this could reflect the large impact of measurement error, it likely also reflects the limited score variability due to small sample size. Further research can elucidate the degree to which measurement error impacts EDPPSR element scores.

Table 4. *Intra-class coefficients.*

Element	**Observed ICC**	**95% CI Lower (2 raters)**	**95% CI Upper (2 raters)**	**Valid *N* (2 raters)**	***p*-value**
A	0.338	-0.266	0.655	38	0.105
B	0.873	0.759	0.933	39	<0.001
C	0.765	0.542	0.88	36	<0.001
D	0.701	0.417	0.847	36	<0.001
E	0.688	0.398	0.839	37	<0.001
F	0.684	0.401	0.834	39	<0.001
G	0.645	0.294	0.822	34	0.002
H	0.526	0.085	0.755	37	0.013
I	0.784	0.579	0.89	36	<0.001
J	0.819	0.643	0.908	35	<0.001
K	0.869	0.749	0.932	38	<0.001
L	0.648	0.314	0.82	36	0.001

Participants - Usability and Ecological Validity Study - 2016 -2017

In addition, to obtain a better sense of the usability and ecological validity (meaningfulness in the real world) of the EDPPSR, we conducted focus groups with teachers with specialized training in teaching engineering design, high school students with a year of engineering design coursework, and engineering college students from under-represented racial/ethnic backgrounds. Focus group #1 was made up of 14 high school students in the 10th grade at one MD high school who had at least one semester of engineering design coursework. Focus group #2 was made up of 8 PLTW master teachers with expertise in teaching engineering design. Focus group #3 was made up of college students from under-represented racial/ethnic populations at one southwestern US university who had no experience with the EDPPSR.

We conducted these focus groups to identify additional ways in which we can ensure that the EDPPSR can be implemented in academic settings and used by students and teachers from diverse backgrounds and contexts. Participants were asked to provide feedback on the EDPPSR content (e.g., wording choice, clarity of concepts presented in rubric, etc.) and various formats or modes of presenting the EDPPSR (e.g., paper versus online/electronic formats).

Methods - Usability and Ecological Validity Study - 2016 - 2017

Qualitative interview data were analyzed using a modified Consensual Qualitative Research method [19].

Results

The EDPPSR was created by engineering and education experts across the country over the course of several years, providing evidence of the relevance and representativeness of the rubric. Using the unified construct validity framework, additional expert reviewers (experts in engineering design) provided evidence supporting the content. The focus group data we gathered was intended to provide feedback for revising and enhancing the content, format, and usability of the EDPPSR rather than more common types of validity evidence.

Results - Usability and Ecological Validity Study - 2016-2017

Focus group #1 students indicated that although the content and wording of the EDPPSR was relatively clear and understandable to them, they felt that this might not be the case for students without prior engineering design coursework – that the EDPPSR in its current form and content might not be suitable for those new to engineering design. In addition, students felt that the rating point descriptors included vague operationalizations of performance. For example, students pointed out that some score point descriptors in the rubric use the term “sufficient” without providing concrete examples of what would be a sufficient level of performance. Students suggested replacing vague terms (e.g., sufficient) with actual number or more concrete terms that provide students with a clearer sense of what is required to demonstrate proficiency in the engineering design process. Students also felt that the EDPPSR score point descriptors and descriptions of EDPPSR elements were too wordy and included too much jargon. Students felt that a more concise bullet-point format of the EDPPSR score descriptors and description of elements would be more user friendly.

Overall, students felt that the EDPPSR and MyDesign concepts were relevant and helpful but felt that revisions to the current content would be beneficial.

Focus group #2 teachers were interviewed in order to obtain their feedback on (a) how they actually use the EDPPSR in their teaching, curriculum development and student evaluation, (b) potential barriers associated with incorporating the EDPPSR in schools, (c) student experiences using the EDPPSR in engineering design projects, and (d) how they might enhance the quality and utility of the EDPPSR.

(a) Teachers use the EDPPSR in curriculum development, instruction, and student evaluation. Some teachers felt that using the EDPPSR was challenging because many of the words in the score descriptors are "so subjective". Some also felt that although the goal of making a standardized and generalizable rubric is advantageous, it is very difficult to articulate one set of guidelines that is applicable across diverse students and projects. Some found the annotated EDPPSR training materials to be very helpful teaching resource. There was also agreement that the EDPPSR could be enhanced by making the language more concise.

(b) One barrier to implementing the EDPPSR in their classrooms was that it was difficult to instruct students in the entire EDPPSR given the limited time in the academic calendar – that there was not enough time to adequately cover all of the EDPPSR elements.

(c) One teacher indicated that although students actively use the EDPPSR, the way in which they use it is not necessarily in keeping with its intended uses. For example, students tend to use the EDPPSR as a guide to determine what grade they might achieve as opposed to using it as a learning guide. Teachers also reported a number of ways in which students benefited from using the EDPPSR. Another teacher found that the EDPPSR was fostering collaboration across students in unique ways such as sharing EDPPSR portfolio work with students in other schools and using the EDPPSR to provide other students feedback. Students also use the EDPPSR to evaluate their own work.

(d) There was general agreement that providing more concise examples (e.g., in the annotated training materials) would be helpful. Some felt that providing a glossary of terms used in the EDPPSR would be beneficial. Teachers felt that the score point descriptors could be greatly strengthened by replacing ambiguous terms (e.g., sufficient; consistently) with terms that more clearly quantify and differentiate levels of performance. Teachers also felt that an online version of the EDPPSR would be beneficial. Teachers also felt that more training materials on the EDPPSR and Innovation Portal would be helpful.

In Focus group #3, college students from under-represented racial/ethnic populations and no experience with the EDPPSR were introduced to the rubric and asked about their initial impressions about the content and utility of the rubric. There was strong agreement among students that the EDPPSR would be very appreciated and helpful in the engineering design courses (instructors do not provide rubrics). For example, one student indicated that she had points deducted on a recent design project, which was an assignment with unclear expectations and guidelines. This student felt that a rubric, like the EDPPSR, would have prevented her from losing points. Students felt that there were many ways in which to improve the EDPPSR. Many felt that it was difficult to differentiate between the different levels of performance based on current score point descriptors and that it was very difficult to quantify performance without numbers (quantifications) in the score point descriptors. Students also felt that providing examples to many terms would be very helpful (e.g., clarifying what makes a source credible). Students felt that providing definitions and/or a glossary of terms would be important. Some students felt that there were concepts (e.g., STEM principles) that could use further explanation.

Positionality

We recognize that our backgrounds and experiences may have informed the study and findings. The lead author participated in the growth of the EDPPSR from an idea to its original inception, helping to create the rubric itself. She then implemented its usage in out-of-school settings to gather data for these studies. She participated in the workshops leading to reliability scoring. As the current co-Director of Engineering for US All (e4usa.org), she now leads the implementation of the EDPPSR through e4usa and the related development of the MyDesign® tool created to aid in classroom implementation. The second author, a nationally recognized assessment specialist who served as a consultant on several grants related to the EDPPSR, was responsible for leading the extensive revision of the first draft of the EDPPSR to the version underlying this study (see Appendix A) and for designing, conducting, and reporting on all scoring workshops and developing associated materials described in this paper. The senior author led this project from its inception, leading the creation of the EDPPSR to overseeing these validity and reliability studies.

Discussion

The EDPPSR was developed in part to assist the student, teacher, event organizer, and other advisors to organize the design process systematically to produce benchmarked evidence of successful use of the engineering design process. Users can create, maintain, expand, and benchmark their design portfolios by applying the EDPPSR process steps. The generated and reported evidence can be from across grade levels (9-12) and through university that span formal and informal education and learning school environments, demonstrating the versatility of the EDPPSR.

Reliability

Over the course of the 2013 and 2015 workshops, the anchor set for each element at each score level has been generated for scores of 0 through 4 for almost all elements. Scores of 5 remain difficult to locate and are missing from the anchor set for Element G-J and L. It is likely that more university level, particularly at a senior design level, portfolios would need to be obtained and scored to complete the anchor set at the score level of 5. The establishment of Training Sets #1 and #2 has been completed, with scorers moving to greater score agreement from Training Set #1 to #2.

The bar at which one judges the ICC results is important to note. Many rubrics are judged at the more stringent 0.80 figure as noted in [17], but there are others, including Arter [18], who set the bar lower. We believe that Arter's criteria apply better to a rubric with a broader scale such as the EDPPSR (e.g., 6 points rather than 3 or 4), allowing as they do for a target for both exact and adjacent agreement. Lower ICC values, as noted, may be suggestive of something problematic in the criteria for those elements (Elements A and H). In the case of Element H (Prototype testing and data collection plan), the frequency of discrepant scores may support the idea that the scoring criteria may be ambiguous or that there needs to be more consensus in raters' conceptual understanding of this element. However, a review of feedback from raters over the course of the research to date does not point to a larger-than-average number of questions or concerns about this element, which one would expect to find if the criteria were problematic. Furthermore, while there were 10 instances of discrepant scores for Element H among the 45 portfolios scored during the workshop—which might be regarded as support for the idea that there are problems with the criteria— several Elements with acceptable ICC values had a higher number of discrepant scores (14 for Element F and 11 for Element G).

Element A might also appear problematic, when the number of instances of discrepant scores is considered along with the lower ICC value for that element. However, a closer look at score records for instances when Element A required a third reading suggests that most score discrepancies involved only a few of the team members, one of whom tended to score overly high and another who tended to score overly low. There was another team member whose scores disagreed with another rater by more than one point on four occasions, whose scores were confirmed (either exactly or via adjacent agreement) through the third reading process.

Validity

Remembering that the EDPPSR was developed by reference to the literature on the steps of the design process through 15 focus groups and workshops including over 200 expert teachers, faculty and researchers in performance based, portfolio rubrics and assessments, we demonstrate evidence of the relevance and representativeness of the rubric. Using the unified construct validity framework, additional expert reviewers (experts in engineering design) provided evidence supporting the content. The focus group data we gathered was intended to provide feedback for revising and enhancing the content, format, and usability of the EDPPSR rather than more common types of validity evidence. This study adds some evidence of the usability and ecological validity (meaningfulness in the real world) of the EDPPSR. The data also point out areas of potential concern around the accessibility of the language used in the EDPPSR, particularly to students and teachers who are new to engineering. Some terminology and elements may require additional documentation or revision to remove perceived subjectivity.

Conclusion

This paper presents empirical evidence that supports the application of the EDPPSR as a guiding tool to examine, validate, and grade design work products. The EDPPSR has been shown to be a reliable and valid instrument. Individual and team uniquely created design artifacts can be evaluated, benchmarked and compared by the broadly applied EDPPSR.

Based on these results, numerous next steps exist including creating an electronic learning management system that facilitates organization of large groups of students engaged in engineering design activities based on the EDPPSR. This system must be tested in numerous educational settings. As many educators noted, the holistic system is challenging at times and parts of the rubric's language are subjective and hard to quantify. Improvements could be made by breaking each holistic Element into sub-sections, each with its own rubric. These smaller rubrics could be improved by making its language more objective and quantifiable where possible. When this is complete, follow-up validity and reliability studies will need to be completed. Breaking the rubric down will allow for more flexibility for teachers with their own educational strategies and different state standards.

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Appendix A. The Engineering Design Process Portfolio Scoring Rubric (EDPPSR).

Engineering Design Process Portfolio Scoring Rubric

(August 2011 version of EDPPSR)

About the Portfolio

The Engineering Design Process Portfolio is intended to document the 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 three overarching facets of the design process: reflection, iteration, and articulation of limitations.

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.

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.

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 your articulation of limitations and the means of addressing them that you propose and justify.

Engineering Design Process Portfolio Scoring Rubric
Component and Element Titles

Component I: Presenting and Justifying a Problem and Solution Requirements

Element A: Presentation and justification of the problem
Element B. Documentation and analysis of prior solution attempts
Element C. Presentation and justification of solution design requirements

Component II: Generating and Defending an Original Solution

Element D: Design concept generation, analysis, and selection
Element E: Application of STEM principles and practices
Element F: Consideration of design viability

Component III: Constructing and Testing a Prototype

Element G: Construction of a testable prototype
Element H: Prototype testing and data collection plan
Element I: Testing, data collection and analysis

Component IV: Evaluation, Reflection, and Recommendations

Element J: Documentation of external evaluation
Element K: Reflection on the design project
Element L: Presentation of designer's recommendations

Component V: Documenting and Presenting the Project

Element M: Presentation of the project portfolio
Element N: Writing like an Engineer

Please Note: Elements M and N do not appear as a TAB on the Innovation Portal as these elements are intended to be scored based on the portfolio work as a whole rather than "Element by Element" The evidence for these elements then, rests in the combined collection of all of the other elements.

Component I: Presenting and Justifying a Problem and Solution Requirements

Element A: Presentation and justification of the problem

5 The problem is clearly and objectively identified and defined with considerable depth, and it is well elaborated with specific detail; the justification of the problem highlights the concerns of many primary stakeholders and is based on comprehensive, timely, and consistently credible sources; it offers consistently objective detail from which multiple measurable design requirements can be determined.

4 The problem is clearly and objectively identified and defined with some depth, and it is generally elaborated with specific detail; the justification of the problem highlights the concerns of some primary stakeholders and is based on various timely and generally credible sources; it offers generally objective detail from which multiple measurable design requirements can be determined.

3 The problem is somewhat clearly and objectively identified and defined with adequate depth, and it is sometimes elaborated with specific detail, although some information intended as elaboration may be imprecise or general; the justification of the problem highlights the concerns of at least a few primary stakeholders and is based on at least a few sources which are timely and credible; although not all information included may be objective, the justification of the problem offers enough objective detail to allow at least a few measurable design requirements to be determined.

2 The problem is identified only somewhat clearly and/or objectively and defined in a manner that is somewhat superficial and/or minimally elaborated with specific detail; the justification of the problem highlights the concerns of only one or two primary stakeholders and/or may be based on insufficient sources or ones that are outdated or of dubious credibility; although little information included is objective, the justification of the problem offers enough objective detail to allow at least a few design requirements to be determined; however, these may not be ones that are measurable.

1 The identification and/or definition of the problem is unclear, is unelaborated, and/or is clearly subjective; any intended justification of the problem does not highlight the concerns of any primary stakeholders and/or is based on sources that are overly general, outdated, and/or of dubious credibility; information included is insufficient to allow for the determination any measurable design requirements.

0 The identification and/or definition of the problem are missing OR cannot be inferred from information included. A justification of the problem is missing, cannot be inferred from information included as evidence, OR is essentially only the opinion of the researcher.

Element B. Documentation and analysis of prior solution attempts

5 Documentation of plausible prior attempts to solve the problem and/or related problems is drawn from a wide array of clearly identified and consistently credible sources; the analysis of past and current attempts to solve the problem-including both strengths and shortcomings- is consistently clear, detailed, and supported by relevant data.

4 Documentation of existing attempts to solve the problem and/or related problems is drawn from a variety of clearly identified and consistently credible sources; the analysis of past and current attempts to solve the problem-including both strengths and shortcomings-is clear and is generally detailed and supported by relevant data.

3 Documentation of existing attempts to solve the problem and/or related problems is drawn from several-but not necessarily varied-clearly identified and generally credible sources; the analysis of past and current attempts to solve the problem-including both strengths and shortcomings-is generally clear and contains some detail and relevant supporting data.

2 Documentation of existing attempts to solve the problem and/or related problems is drawn from a limited number of sources, some of which may not be clearly identified and/or credible; the analysis of past and current attempts to solve the problem-including strengths and/or shortcomings-is overly general and contains little detail and/or relevant supporting data.

1 Documentation of existing attempts to solve the problem and/or related problems is drawn from only one or two sources that may not be clearly identified and/or credible; the analysis of past and current attempts to solve the problem-including strengths and/or shortcomings-is vague and is missing any relevant details and/or relevant supporting data.

0 Documentation of existing attempts to solve the problem and/or related problems is missing or minimal (a single source that is not clearly identified and/or credible) OR cannot be inferred from information intended as analysis of past and/or current attempts to solve the problem.

Element C. Presentation and justification of solution design requirements

5 Design requirements are listed and prioritized, and they are consistently clear and detailed; these design requirements presented are consistently objective, measurable, and they would be highly likely to lead to a tangible and viable solution to the problem identified; there is evidence that requirements represent the needs of, and have been validated by, many if not all primary stakeholder groups.

4 Design requirements are listed and prioritized, and they are generally clear and detailed; these design requirements presented are nearly always objective and measurable, and they would be likely to lead to a tangible and viable solution to the problem identified; there is evidence that requirements represent the needs of, and have been validated by, several primary stakeholder groups.

3 Design requirements are listed and prioritized, and they are generally clear and somewhat detailed; these design requirements presented are generally objective and measurable, and they have the potential to lead to a tangible and viable solution to the problem identified; there is evidence that requirements represent the needs of, and have been validated by, at least a few primary stakeholder groups.

2 Design requirements are listed and prioritized, but some/all of these may be incomplete and/or lack specificity; these design requirements may be only sometimes objective and/or measurable, and it is not clear that they will lead to a tangible and viable solution to the problem identified; there is evidence that the requirements represent the needs, of/and or have been validated by, only one primary stakeholder group.

1 An attempt is made to list, format, and prioritize requirements, but these may be partial and/or overly general, making them insufficiently measurable to support a viable solution to the problem identified; there is no evidence that the requirements represent the needs of, or have been validated by, any primary stakeholder groups.

0 Design requirements are either not presented or are too vague to be used to outline the measurable attributes of a possible design solution to the problem identified.

Component II: Generating and Defending an Original Solution

Element D: Design concept generation, analysis, and selection

5 The process for generating and comparing possible design solutions was comprehensive, iterative, and consistently defensible, making a viable and well-justified design highly likely; the design solution ultimately chosen was well-justified and demonstrated attention to all design requirements; the plan of action has considerable merit and would easily support repetition and testing for effectiveness by others.

4 The process for generating and comparing possible design solutions was thorough, iterative, and generally defensible, making a viable design likely; the design solution chosen was justified and demonstrated attention to most if not all design requirements; the plan of action would support repetition and testing for effectiveness by others.

3 The process for generating and comparing possible design solutions was adequate and generally iterative and defensible, making a viable design possible; the choice of design solution was explained with reference to at least some design requirements; the plan of action might not clearly or fully support repetition and testing for effectiveness by others.

2 The process for generating a possible design solution was partial or overly general and only somewhat iterative and/or defensible, raising issues with the viability of the design solution chosen; that solution was not sufficiently explained with reference to design requirements; there is insufficient detail to allow for testing for replication of results.

1 The process for generating a possible design solution was incomplete and was only minimally iterative and/or defensible; any attempted explanation for the design solution chosen lacked support related to design requirements and cannot be tested.

0 There is no evidence an attempt to arrive at a design solution through an iterative process based on design requirements.

Element E: Application of STEM principles and practices

5 The proposed solution is well-substantiated with STEM principles and practices applicable to all or nearly all design requirements and functional claims; there is substantial evidence that the application of those principles and practices by the student or a suitable alternate has been reviewed by two or more experts (qualified consultants and/or project mentors) and that those reviews provide confirmation (verification) or detail necessary to inform a corrective response.

4 The proposed solution is generally substantiated with STEM principles and practices applicable to some design requirements and functional claims; there is some evidence that the application of those principles and practices by the student or a suitable alternate has been reviewed by at least two experts (qualified consultants and/or project mentors) and that those reviews provide confirmation (verification) or some detail necessary to inform a corrective response.

3 The proposed solution is partially substantiated with STEM principles and practices applicable to at least a few design requirements and functional claims; there is some evidence that the application of those principles and practices by the student or a suitable alternate has been reviewed by at least one expert (qualified consultant or project mentor) but this review may not provide clear confirmation (verification) or at least some detail to inform a corrective response.

2 The proposed solution is minimally substantiated with STEM principles and practices applicable to at least a few design requirements and functional claims; there is minimal evidence that the application of those principles and practices by the student or a suitable alternate has been reviewed by at least one expert (qualified consultant or project mentor) but there is no evidence of confirmation (verification) or any detail to inform a corrective response.

1 The proposed solution is minimally substantiated with STEM principles or practices applicable to at least a few design requirements and functional claims; however, there is no evidence that the application of those principles and practices by the student or a suitable alternate has been reviewed by an expert (qualified consultant or project mentor).

0 The proposed solution is not substantiated with STEM principles or practices applicable to any design requirements and/or functional claims.

Element F: Consideration of design viability

5 The proposed design was carefully reviewed based on several relevant extra-functional considerations; a judgment about design viability based on those considerations-the capacity of the proposed solution to address the problem-is clearly realistic and well supported with credible evidence.

4 The proposed design was adequately reviewed based on several relevant extra-functional considerations; a judgment about design viability based on those considerations-the capacity of the proposed solution to address the problem-is generally realistic and adequately supported with credible evidence.

3 The proposed design was partially reviewed based on one or two relevant extra-functional considerations; a judgment about design viability based on those considerations-the capacity of the proposed solution to address the problem-is only somewhat/sometimes realistic and is only partially supported with credible evidence.

2 The proposed design was superficially reviewed based on one or two relevant extra-functional considerations; a judgment about design viability based on those considerations-the capacity of the proposed solution to address the problem-may be generally although not completely unrealistic and/or may be inadequately supported with credible evidence.

1 The proposed design was superficially reviewed based on one or two extra-functional considerations of marginal relevance; a judgment about design viability based on those considerations-the capacity of the proposed solution to address the problem-may be unrealistic and/or not supported with any credible evidence.

0 There is no evidence provided that the proposed design was reviewed based on any extra- functional considerations.

Component III: Constructing and Testing a Prototype

Element G: Construction of a testable prototype

5 The final prototype iteration is clearly and fully explained and is constructed with enough detail to assure that objective data on all or nearly all design requirements could be determined; all attributes (sub-systems) of the unique solution that can be tested or modeled mathematically are addressed and a well-supported justification is provided for those that cannot be tested or modeled mathematically and thus require expert review.

4 The final prototype iteration is clearly and adequately explained and is constructed with enough detail to assure that objective data on many design requirements could be determined; most attributes (sub-systems) of the unique solution that can be tested or modeled mathematically are addressed and a generally supported justification is provided for those that cannot be tested or modeled mathematically and thus require expert review.

3 The final prototype iteration is clearly and adequately explained and is constructed with enough detail to assure that objective data on some design requirements could be determined; some attributes (sub-systems) of the unique solution that can be tested or modeled mathematically are addressed and an adequately supported justification is provided for those that cannot be tested or modeled mathematically and thus require expert review.

2 The final prototype iteration is explained only somewhat clearly and/or completely and is constructed with enough detail to assure that objective data on at least a few design requirements could be determined; a few attributes (sub-systems) of the unique solution that can be tested or modeled mathematically are addressed but there may be insufficient justification for those that cannot be tested or modeled mathematically and thus require expert review.

1 The final prototype iteration is only minimally explained and/or is not constructed with enough detail to assure that objective data on at least one design requirements could be determined; no more than one attribute (sub-system) of the unique solution that can be tested or modeled mathematically is addressed and any attempt at justification for those that cannot be tested or modeled mathematically and thus require expert review is missing.

0 Any attempt to explain the final prototype iteration is unclear or is missing altogether; there is no evidence that the prototype would facilitate testing by suitable means for any of the design requirements.

Element H: Prototype testing and data collection plan

5 The testing plan addresses all or nearly all of the high priority design requirements by effectively describing the conduct (through physical and/or mathematical modeling) of those tests that are feasible based on the instructional context and providing for others a logical and well-developed explanation confirmed by one or more field experts of how testing would yield objective data regarding the effectiveness of the design.

4 The testing plan addresses many of the high priority design requirements by describing in a generally effective way the conduct (through physical and/or mathematical modeling) of those tests that are feasible based on the instructional context and providing for others a logical and generally developed explanation confirmed by one or more field experts of how testing would yield objective data regarding the effectiveness of the design.

3 The testing plan addresses some of the high priority design requirements by adequately describing the conduct (through physical and/or mathematical modeling) of those tests that are feasible based on the instructional context and providing for others a generally logical and adequately developed explanation confirmed by one or more field experts of how testing would yield objective data regarding the effectiveness of the design.

2 The testing plan addresses a few of the high priority design requirements by at least partially describing the conduct (through physical and/or mathematical modeling) of those tests that are feasible based on the instructional context and providing for others an only somewhat logical and/or partially developed explanation confirmed by one or more field experts of how testing would yield objective data regarding the effectiveness of the design.

1 The testing plan addresses one of the high priority design requirements by describing at least minimally the conduct (through physical and/or mathematical modeling) of a test that is feasible based on the instructional context and/or providing for an at least generally logical and/or partially developed explanation of how testing would yield objective data regarding the effectiveness of the design; confirmation of that explanation by even one field expert may be missing.

0 Any testing plan included fails to address at least one of the high priority design requirements by describing at least minimally the conduct (through physical and/or mathematical modeling) of a test that is feasible based on the instructional context and/or providing for an at least generally logical and/or partially developed explanation of how testing would yield objective data regarding the effectiveness of the design; OR a testing plan is missing altogether.

Element I: Testing, data collection and analysis

5 Through the conduct of several tests for high priority requirements that are reasonable based on instructional contexts, or through physical or mathematical modeling, the student demonstrates considerable understanding of testing procedure, including the gathering and analysis of resultant data; the analysis of the effectiveness with which the design met stated goals includes a consistently detailed explanation [and summary] of the data from each portion of the testing procedure and from expert reviews, generously supported by pictures, graphs, charts and other visuals; the analysis includes an overall summary of the implications of all data for proceeding with the design and solving the problem.

4 Through the conduct of several tests for high priority requirements that are reasonable based on instructional contexts, or through physical or mathematical modeling, the student demonstrates ample understanding of testing procedure, including the gathering and analysis of resultant data; the analysis of the effectiveness with which the design met stated goals includes a generally detailed explanation [and summary] of the data from each portion of the testing procedure and from expert reviews, generally supported by pictures, graphs, charts and other visuals; the analysis includes an overall summary of the implications of most if not all of the data for proceeding with the design and solving the problem.

3 Through the conduct of a few tests for high priority requirements that are reasonable based on instructional contexts, or through physical or mathematical modeling, the student demonstrates adequate understanding of testing procedure, including the gathering and analysis of resultant data; the analysis of the effectiveness with which the design met stated goals includes a somewhat detailed explanation [and summary] of the data from each portion of the testing procedure and from expert reviews, at least somewhat supported by pictures, graphs, charts and other visuals; the analysis includes a summary of the implications of at least some of the data for proceeding with the design and solving the problem.

2 Through the conduct of one or two tests for high priority requirements that are reasonable based on instructional contexts, or through physical or mathematical modeling, the student demonstrates partial or overly general understanding of testing procedure, including the gathering and analysis of resultant data; the analysis of the effectiveness with which the design met stated goals includes a partial explanation [and summary] of the data (partially complete and/or partially correct), at least minimally supported by pictures, graphs, charts and other visuals; the analysis includes a partial and/or overly-general summary of the implications of at least some of the data for proceeding with the design and solving the problem.

1 Through the conduct of one or two tests for requirements (which may or may not be high priority) that are reasonable based on instructional contexts, or through physical or mathematical modeling, the student demonstrates minimal understanding of testing procedure, including the gathering and analysis of resultant data; the analysis of the effectiveness with which the design met stated goals includes an attempted explanation [and summary] of the data but may not be supported by any pictures, graphs, charts or other visuals; the analysis may be missing even a partial and/or overly-general summary of the implications of any of the data for proceeding with the design and solving the problem.

0 Any test(s) for requirement(s) or attempts at physical or mathematical modeling fail to demonstrate even minimal understanding of testing procedure, including the gathering and analysis of resultant data; OR there is no evidence of testing or physical or mathematical modeling to address any requirements.

Component IV: Evaluation, Reflection, and Recommendations

Element J: Documentation of external evaluation

5 Documentation of project evaluation by multiple, demonstrably qualified stakeholders and field experts is presented and is synthesized in a consistently specific, detailed, and thorough way; documentation is sufficient in two or more categories to yield meaningful analysis of that evaluation data; the synthesis of evaluations consistently addresses evaluators' specific questions, concerns, and opinions related to design requirements.

4 Documentation of project evaluation by two or more demonstrably qualified stakeholders and field experts is presented and is synthesized in a generally specific, detailed, and thorough way; documentation is sufficient in at least one category to yield a meaningful analysis of that evaluation data; the synthesis of evaluations generally addresses evaluators' specific questions, concerns, and opinions related to design requirements.

3 Documentation of project evaluation by three or four demonstrably qualified stakeholders and/or field experts is presented and is synthesized in a somewhat specific and detailed way, but may not be thorough; documentation may not be sufficient in any category to yield a meaningful analysis of that evaluation data; the synthesis of evaluations addresses at least some of evaluators' specific questions, concerns, and opinions related to design requirements.

2 Documentation of project evaluation by two or three representatives of stakeholders and/or field experts (some of whom may not be demonstrably qualified) is presented and is synthesized in a somewhat specific and/or detailed but incomplete or overly general way; the synthesis of evaluations addresses at least a few of evaluators' specific questions, concerns, and/or opinions related to design requirements.

1 Documentation of project evaluation by one or two representatives of stakeholders and/or field experts is presented but synthesis is sparse, with few specifics/details; the synthesis of evaluations addresses only one or two of an evaluator's questions, concerns, and/or opinions related to design requirements.

0 Documentation of project evaluation by any representative stakeholder or field expert is non- existent OR if included is minimal; synthesis is minimal or missing and if present, does not address any questions, concerns, or opinions of an evaluator related to design requirements.

Element K: Reflection on the design project

5 The project designer provides a consistently clear, insightful, and comprehensive reflection on, and value judgment of, each major step in the project; the reflection includes a substantive summary of lessons learned that would be clearly useful to others attempting the same or similar project.

4 The project designer provides a clear, insightful and well-developed reflection on, and value judgment of, each major step in the project; the reflection includes a summary of lessons learned that would be clearly useful to others attempting the same or similar project.

3 The project designer provides a generally clear and insightful, adequately-developed reflection on, and value judgment of, major steps in the project, although one or two steps may be addressed in a more cursory manner; the reflection includes a summary of lessons learned, at least most of which would be useful to others attempting the same or similar project.

2 The project designer provides a generally clear, at least somewhat insightful, and partially developed reflection on, and value judgment of, most if not all of the major steps in the project; the reflection includes some lessons learned which would be useful to others attempting the same or similar project.

1 The project designer provides a reflection on, and value judgment of, at least some of the major steps in the project, although the reflection may be partial, overly-general and/or superficial; the reflection includes a few lessons learned of which at least one would be useful to others attempting the same or similar project.

0 The project designer attempts a reflection on, and value judgment of, at least one or two of the major steps in the project, although the reflection may be minimal, unclear, and/or extremely superficial; any lessons learned are unclear and/or of no likely use to others attempting the same or similar project; OR there is no evidence of a reflection and/or lessons learned.

Element L: Presentation of designer's recommendations

5 The project designer includes consistently detailed and salient recommendations regarding the conduct of the same or similar project in the future; recommendations include caveats as warranted and specific ways the project could be improved with consistently detailed plans for the implementation of those improvements

4 The project designer includes generally detailed and salient recommendations regarding the conduct of the same or similar project in the future; recommendations include caveats as warranted and specific ways the project could be improved with generally detailed plans for the implementation of those improvements

3 The project designer includes a few detailed and salient recommendations regarding the conduct of the same or similar project in the future; recommendations include some specific ways the project could be improved along with what may be only minimally detailed plans for the implementation of those improvements and may also include one or two caveats for others

2 The project designer includes recommendations regarding the conduct of the same or similar project in the future; recommendations may include some specific ways the project could be improved but plans for the implementation of those improvements may be missing OR the recommendations (with or without plans) may be partial and/or overly general.

1 The project designer includes one or two overly general and/or questionably relevant recommendations regarding the conduct of the same or similar project in the future; any plans for implementation included are vague/unclear or minimally related to the recommendations provided.

0 The project designer includes one or two recommendations (with or without plans) that bear little/no relation to the conduct of the same or similar project in the future OR fails to offer any recommendations or plans regarding the conduct of the same or similar project in the future.

Component V: Documenting and Presenting the Project

Element M: Presentation of the project portfolio

5 The portfolio provides consistently clear, detailed, and extensive documentation of the design process and project that would with certainty facilitate subsequent replication and refinement by the designer(s) and/or others; attention to audience and purpose was abundantly evident in the choice of mode(s) of presentation, professionalism of style and tone, and the variety, quality, and suitability of supporting materials.

4 The portfolio provides clear, generally detailed and thorough documentation of the design process and project that would be likely to facilitate subsequent replication and refinement by the designer(s) and/or others; attention to audience and purpose was evident in the choice of mode(s) of presentation, professionalism of style and tone, and the variety, quality, and suitability of supporting materials.

3 The portfolio provides generally clear and thorough documentation of the design process and project that would be likely to facilitate subsequent replication and refinement by the designer(s) and/or others, although there may be some minor omissions or inconsistencies; attention to audience and purpose was generally-but not always--evident in the choice of mode(s) of presentation, professionalism of style and tone, and the variety, quality, and suitability of supporting materials.

2 The portfolio provides partial or sometimes overly general documentation of the design process and project that would be likely to facilitate subsequent replication and refinement by the designer(s) and/or others; attention to audience and purpose was only sometimes/somewhat evident in the choice of mode(s) of presentation, professionalism of style and tone, and the variety, quality, and suitability of supporting materials.

1 The portfolio provides minimal documentation of the design process and project that would be likely to facilitate subsequent replication and refinement by the designer(s) and/or others; attention to audience and purpose was rarely evident in the choice of mode(s) of presentation, professionalism of style and tone, and the variety, quality, and suitability of supporting materials.

0 The portfolio attempts to document the design process and project but little/none of that information supports subsequent replication and refinement by the designer(s) and/or others; little/no attention to audience and purpose was evident in the choice of mode(s) of presentation, professionalism of style and tone, or the variety, quality, and suitability of any supporting materials included.

Element N: Writing like an Engineer

5 Abundant evidence of the ability to write consistently clear and well organized texts that are developed to the fullest degree suitable for the audience and purposes intended (to explain, question, persuade, etc.); texts consistently demonstrate the ability to adjust language, style and tone to address the needs and interests of a variety of audiences (e.g., expert, informed, general/lay audience) and to use a wide variety of forms which are commonplace among STEM disciplines (e.g., notes, descriptive/narrative accounts, research reports); where required by convention, appropriate documentation in standardized form (e.g., APA) is consistently evident.

4 Evidence of the ability to write clear and well organized texts that are generally well-developed for the audience and purposes intended (to explain, question, persuade, etc.); texts generally demonstrate the ability to adjust language, style and tone to address the needs and interests of a variety of audiences (e.g., expert, informed, general/lay audience) with minor exceptions and demonstrate the ability to use a variety of forms which are commonplace among STEM disciplines (e.g., notes, descriptive/narrative accounts, research reports); where required by convention, appropriate documentation in standardized form (e.g., APA) is generally evident.

3 Adequate evidence of the ability to write usually clear and generally organized texts that are at least partially developed for the audience and purposes intended (to explain, question, persuade, etc.); texts demonstrate the ability to adjust language, style and tone to address the needs and interests of several different audiences (e.g., expert, informed, general/lay audience) but may be unsuccessful at doing so on occasion; texts demonstrate the ability to use a several different forms which are commonplace among STEM disciplines; where required by convention, appropriate documentation in standardized form (e.g., APA) is sometimes evident, although attempts at documentation may reveal minor errors;

2 Only some evidence of the ability to write clear and organized texts that are at least partially developed for the audience and purposes intended (to explain, question, persuade, etc.); texts demonstrate some ability to adjust language, style and tone to address the needs and interests of at least two different audiences (e.g., expert, informed, general/lay audience) but adjustments are not evident-although warranted-in a number of instances; texts demonstrate the ability to use at least two different forms which are commonplace among STEM disciplines; where required by convention, appropriate documentation in standardized form (e.g., APA) is frequently missing or incorrect.

1 Little evidence of the ability to write clear and organized texts that are at least partially developed for the audience and purposes intended (to explain, question, persuade, etc.); texts demonstrate little ability to adjust language, style and tone to address the needs and interests of at least two different audiences (e.g., expert, informed, general/lay audience) but many adjustments are not evident- although warranted;

texts demonstrate the attempt to use at least two different forms which are commonplace among STEM disciplines; appropriate documentation in standardized form (e.g., APA) is usually missing or incorrect.

0 Virtually no evidence of the ability to write even somewhat clear and organized texts that are developed for the audience and purposes intended (to explain, question, persuade, etc.); texts demonstrate virtually no ability to adjust language, style and tone to address the needs and interests of at least two different audiences (e.g., expert, informed, general/lay audience); there may be evidence of an attempt to use at least two different forms which are commonplace among STEM disciplines but these are not correctly differentiated; there is virtually no evidence of any attempt to provide documentation in standardized form where needed.

SCORING NOTES:

Element A: It is conceivable that with elements A and B from the scoring pilot version of the EDPPSR now combined, a score decision may be difficult to make in the event that a student has provided a very clear and objective problem statement but a weak justification (that is, that the entry is 5-like in some ways and 2-like in others. This scenario can be addressed in two ways. One is to revise the element descriptors for 3 and below to convey alternate ways to achieve this level (e.g., add "OR the problem is clearly and objectively identified and defined with considerable depth and is well elaborated with specific detail but the of the problem only highlights the concerns of a few primary stakeholders and/or is based on at least a few sources which are timely and credible"). Alternatively, a scoring rule (an established policy for making a particular score decision) can be established (for example, "When a response is characterized by descriptors for discrepant score points, assign the score at mid-point between them").

Element B: As part of scoring training and/or background information for students and teachers, it should be made clear that past attempts at a solution do not need to directly apply to the problem at hand. Students can refer to solutions from other, analogous or related problem spaces.

To encourage students to go further, and not limit themselves to several tests when they may be interested in and able to do more, we may consider a scoring rule that would allow for additional evidence of proficiency to have a compensatory function; in other words, if for example an entry/set of entries does not provide accurate and thorough data analysis for a particular test but provides evidence of the successful conduct of more than 3-4 tests, that can on balance lead to the assignment of the higher score.

GLOSSARY (in progress):

Attribute: characteristic of a design sub-system.

Design requirements: characteristics essential to the viability of the solution to the design problem (what you must do or attend to or the design will fail); design requirements include the constraints inherent in the design solution and may be supplemented with goals and parameters; design requirements may be functional and/or extra-functional.

Prototype: The new thing or process-either in its entirety or in pieces-that is envisioned or actually created in the course of engaging in the engineering design process.

Stakeholder: anyone with first hand experience related to the problem and/or who are clearly impacted by the problem or any proposed solution; stakeholders include but are not limited to end- users.

Appendix B: October 2013 Scoring Workgroup Score Data

Portfolio	Exact Agreement	Adjacent Agreement	Discrepant Agreement
1 *Back Pain*	D(0), E(0), F (0), G (0), I(1), K(0)	C(1,2), H(1,2), L(1/0)	A(2,5[2]), B(3,0/1[2]), (J(2-,0 [2])
2 *Check Engine Light*	J (4)	A(5-,4+), C(3,2), D(4+,5), F(3+,2), G(4,3),	B(5/4,2+[5]), E(2/3,4[5], H(4/5,3[5]), I(4,2[4]), K(3/4,5[4], L(3,5[4])
3 *Colorblind Driving*	B(2), D(2), J(0), K(0)	A(4,3), C(3,2), E(1,3), F(4,3), G(2,3), I(3,2), L(2,1)	H(3,1 [4])
4 *Cooled Automotive Air Intake*	I(3)	A(2-/1+,3-), B (3,2+), C(0+,/1-/1+), D(1/0+,2), E (1/0,1), F(0,1), G(2,3), H(3,2), J(2/1+,1),	K(3/4,1+[3]), L(4,2-[4])
5 *Creo Inc.*	A(2), C(0), E(0), F(0), G(2), H(1), J(0)	B(2,3), D(1,2), I(1,2), L(2,3)	K(1,3[1]
6 *Deep Water Entry of a Canoe*	C(0), F(0), G(0), J(0), K(0)	A(4,3), D(0/1,0), E(0,1-), H(0,1), I(1,0), L(1/0,1-)	B(NA—missing info, 1 [1])
7 *Dog Restraint*	G(1), J(1), K(0)	A(2-,1), B(1,2), C(1,2), H(1,1/2), I(1,1/2), L(1, 0/1)	D(3,1[5]), F(0,2[1])
8 *E-Waste*	A(3), G(3), I(0)	B (3,4), C(0,1), K(2,3)	D(1,4[5]), E(1,3[5]), F(1,3[4++]), H (2,4[_]), J(2,4[5]), L(2,4[2])

9 *Forklift Safety (3 raters)*	E(5)	A(4,5,4), B(5,4,4), C(5,4,5), D(4,5,3/4), F (3/4,5,5), G (4,5,4/5), J(3/4,3,4), K(5,4,5), L(3,4,4)	H (1,3,4), I (2-,3,3/4)
10 *Grilling Safety*	A(4), B(3), C(4), J(1), L(3)	D(2,3), H(3+,2), K(1+,2)	E(4,1[2]), I(4,1[2])
11 *New Carbon Anode Project*	B(3), E(1), H(1), K(1)	A(4,3), C(2,3), D(3,2), F(2,1), G(1,2), I(2,1), L(1,2)	No 3rd ratings needed
12 *Self-Cooling Pillow*	A(3), E(1), F(2), I (2), L(2)	B (4,3), J(3,4)	C(1,3), D(4/NS), G(1,3), H(1NS), K(4,2); no 3rd rating obtained
13 *Shoulder Injury*	A(2), D(2), G(3), H(1), K(3), L(3)	B(2,1), E(1,1/2), I(1,2), J(2,1)	C(1,3/2[2]), F(0,3[0])
14 *Silverbacks*	A(2), B(2), G(2), I(0), J(0), K(0)	D(3,2), E(0,1), H(1,0), L(2,1)	C(1/2, 3-), F(2,0); no 3rd rating obtained
15 *Soft Close Door*	L(1)	A(1,2), B(4,3), C(2,1), E(0,1), F(0,1), G(1,2)	D(0/2[2]), H(4,1[1]), I(4,2[2]), J(4,1[2]), K(3,1 [3/2])
16 *Melonator*	B(2), J(3)	E(0,1), H(1,2+), I(1, 2+), L(3,4)	A(0,3+[0]), C(1+,3+[0]), D(1,3[2]), F(0,2-,[1]), G(0,2[0]), K(2,4[1])
17 *Airless Paint Overspray Control*	C(1), E(0), I(2), L(2)	A(1,2), B(2,2/3), F(2, 1/2), G(3,2-), H(2,3), J(2,1)	D(0,2), K(0,2); no 3rd rating obtained
18 *Ultimate Mobility Aid*	A(1), B(2), G(1), I(1), J(0)	C(1,0), D(1-,2), E(1-,2), F(0+,1), H(1+,2),	K(1,3[2]), L(1+,3[2])

[ ] research portfolio

[ ] 3rd rater in exact agreement with either 1st or 2nd rater

NOTE:

Eligible examples of exact agreement entries for construction of training set(s) after gaps filled in current anchor set (see Appendix):

A: score points 1, 2, 3, 4

B: score points 2, 3

C: score points 0, 1, 4

D: score points 0, 2

E: score points 0, 1

F: score points 0, 2

G: score points 0, 1, 2, 3

H: score point 1

I: score points 0, 1, 2, 3

J: score points 0, 1, 3

K: score points 0, 1, 3

L: score points 1, 2, 3

Appendix C: Progress Towards Building Anchor Set Training Materials

Element	0	1	2	3	4	5
A		Car Lockout	Snowmobile	Snow Clear LED	*Forklift Safety (4+)*	
B	Art. Blood Vessel	Car Lockout	Snow Clear LED	Tree Ice Accum.	*Forklift Safety* (4+)	
C	Posture Correction	Snow Clear LED	Stylus Relief		*Crutch Beverage Holder*	*Forklift Safety*
D	Bicycle Tire Pres.	Emergency Crutch	Posture Correction	Stylus Relief	Thermobile	
E	Bicycle Tire Pres.	Door Speed Control	*Crutch Beverage Holder*	Pool Chem. Delivery		*Forklift Safety*
F	Rain Detection	Posture Correction	Bicycle Tire Pres.		Ladder Accident Prevention	

G	Tree Ice Accum.	Car Window Roll-up	Posture Correction	Reinventing Life Jacket	*Crutch Beverage Holder*	
H	Snow Obstr.	Reinventing Life Jacket	RFID Lockout prevention			
I	Snow Removal	Tree Ice Accum.	Reinventing Life Jacket	Ladder Accident Prevention		
J	Posture Correction	Safe Clean Store	Stylus Relief	Door Speed Control	*Check Engine Light*	
K	Posture Correction	Stylus Relief	Safe Clean Store	Door Speed Control	Extra Lure Safe	*Forklift Safety* (5-)
L	Emergency Crutch	Posture Correction	Safe Clean Store	Stylus Relief		

Key:

[ ]) Needed annotated entry; possible entry source from October 2013 workgroup in *italics*

Appendix D. Training Set #1 Results. 2015.

Score change post-discussion in *italics*; training score post-discussion in **boldface** in first column. **DNU** notes entries that should not be used as training samples because they were deemed to not be sufficiently clear-cut for that purpose.

Element	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11
A (2) **2**	2-	2	1	2 (2 in 2013)	2	1-2	2+	2 (2 in 2013)	2	2	2
B (3) **3-**	2 (3+ in 2013); *3-*	2; *3-*	3 (3 in 2013)	2 (2 in 2013)	4	3	2+ (3 in 2013); *3-*	2 (2 in 2013)	2 (4 in 2014)	3	1; *2*
C (4) **3** **DNU**	3	3	1 (4 in 2013); *2*	2 (2 in 2013)	4	1; *2*	2+ (3 in 2013); *3-*	1; *2*	3	2	2
D (2) **2**	3 (2 in 2013)	4; *2+*	2	1;	3; *2/3*	1-2	2+	4; *3*	2	2	3
E (0) **0**	1 (0 in 2013)	0	0	0 (0 in 2013)	1	1	1 (0 in 2013)	0 (0 in 2013)	1 (1 in 2013)	1	1
F(1**) 1**	1	1	0	2	0	1	3 (gave 1 in 2013)	1	2	1	2
G (2) **2**	2	1	1	2 (2 in 2013)	2	3-; *2*	4-	1 (2 in 2013)	4	2	3

H (1) **2-**	3; *2*	2	3; *2*	2 (1 in 2013)	2	1	3	1 (1 in 2013)	2	2	2
I (2) **3**	3	4; *3*	4 (3 in 2013)	2	1	2/3; *3*	4 (3 in 2013); *3*	4 (4 in 2013); 3	3	3	3
J (4) **2/3 Possibly DNU**	0*; 3*	2	1 (4 in 2013); *2*	2	4; **3**	0-1; *3*	4; 3	3; *2*	3	1; *1+*	2*; 3*
K (1) **1**	1	0	0 (1 in 2013)	0	1	1	1+	1 (1 in 2013)	1	1	2
L (3) **3**	3	1	1	2	3	3	4-	1	3	2	5*; 3*

Appendix E. Training Set #2 Results. 2015.

Score change post-discussion in *italics*; training score post-discussion in **boldface** in first column

Element	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11
A (4) **3**	4; *3*	3	4 (4 in 2013); *3*	4; 3	2	3	2+ (4 in 2013)	3+	4	2+	2
B (2) **2-**	2 (2 in 2013); 2-	3	3	2	0	2-	1+; *2-*	2-	2-/1	1+; *2-*	2-
C (1) **1+**	1+/2-; *1+*	2; *1+*	3 (1 in 2013); *2*	3 (1 in 2013); *2*	1	3	2-/1; *1*	2-; *1+*	1	2+	1
D (4) **5-**	5	5	5 (5 in 2013)	4; *5*	5	4/5	4; *5*	2-; *4*	5-/4+	2	4
E (0) **0**	0	1-	2	2 (0 in 2013); *1*	0	2	1	1	0	1	0
F (2) **2**	2+ (2 in 2013)	2	1	3	1	1	1	2+	2 (2 in 2013)	1-	2
G (4+) **3 /4 Possibly DNU**	3	3-	4 (4 in 2013)	2	5?	3	3+ (5 in 2013)	2	3	4-	3
H (1) **1**	2	2	1	2	1	2	1	1	1	2+	1
I (2) **2**	0; *2-*	2	2	3 (2 in 2013)	2/3-	4-	2-	2-	1-	2	2

J (3) **2**	3	1+	2	2	2	2	1+ (3 in 2013)	1 (2 in 2013)	2-/1+	3	3/2
K (3) **? DNU**	5-	2+	5; *4*	3	½; *2*	3	5	1	3	4+	4
L (2) **2**	1+	3	1	3 (2 in 2013)	1	2	1-	2+	1	2-	3/2

Appendix F. January 2015 Scoring Workshop Score Data

Note: Rater number determines order in which scores appear, in the case of adjacent and discrepant scores.

Portfolio	Exact Agreement	Adjacent Agreement	Discrepant Agreement
001: 2013-New Carbon Anode	F (1), I (2), J (1), K (0)	B (3, 2), C (2, 1), D (0, 1), G (2, 1), H (2, 1),	A (4-, 2- [4]), E (4, 0 [2]), L (0+, 2 [1})
002: Lawn Mower Kick Starter	B (3), C (3), F (0),	A (2+, 3), D (3+, 4), E (4, 3), H (2,1) I (0, 1)	G (4, 2 [4-]), J (2, 0 [1], K (3, 1 [4-]), L (4-, 2 [3])
003: Cracked iPhone Screen	B (3), C (2), D (2), I (3), J (2, K (3)	A (4+, 3), E (0, 1), G (2, 3), H (2, 3), L (2, 3)	F (0, 2 [2-])
004: Humidity Issues on Guam	B (X), E (X), G (X), I (X), J (X), L (X)	C (1, 0), D (2+, 1), K (2, 3)	A (2+, 4+ [1]) F (X, 0 [0]), H (2, X [X])
005: 2013-Melonator	C (2), F (2), K (2), L (2)	B (2, 3), D (4, 3), E (1, 2), G (0, 1), H (2, 3), I (0, 1), J (1+, 2)	A (1, 3 [2])
006: Printed Circuitboard	E (1), G (1), J (X), K (1)	B (3, 2), C (1, 2), D (2, 3), F (3, 2), I (1, 2)	A (4, 2 [1]), H (1, 3 [0]), L (0, 3 [2])
007: 2013-Check Engine Light	A (3), C (2), G (4), I (3), J (2)	B (4, 3), D (4, 3), E (1, 0), H (3+, 2), L (4, 3)	F (3, 0 [2]), K (1, 3 [3])

008: Zero Turn Lawn Mowing	C (2), F (1)	A (2, 3), B (3-, 2), D (3,2), E (0, 1), G (2,1), H (2, 1), I (2,1), J (3, 2), K (2, 3), L (3, 2)	
009: Clean Water	A (2), F (2), G (X), H (X), I (X), J (X), K (X) L (X)	B (4, 3), C (1, 2), D (1, 2), E (1, 2)	
010: Sewage Problem	B (1), E (0), G (X), H (X), I (X), J (X), K (X), L (X)	A (1, 2), C (0, 1), D (0, 1), F (0, 1)	
011: AVENGINEERING	H (3), K (0), L (2)	A (3, 2), B (4,3), C (3, 2), D (2, 3), E (1, 0), I (2, 3), J (3, 2)	F (3, 1 [2]), G (5, 3 [4])
012: Bio-pharmaceuticals	B (2), G (X), I (X), J (X), L (2)	C (2, 1), K (1, 0)	A (0, 2 [2]), D (1, 3 [0]), E (1, 5 [0]), F (3, 1 [2]), H (2, 0 [1-])
013: Storing Nuclear Waste	E (X), G (X), H (X), I (X), J (X)	A (3, 4), B (4, 5), F (4, 5)	C (2, 4 [2]), D (1, 5 [0]), K (2, 4 [3]), L (0, 5 [2])
014: 2013-E-Waste	F (3), G (X), L (4)	A (2, 3), B (2, 3), C (3, 4), E (5, 4), K (4, 3)	D (2, 5 [4]), H (1, 3 [3]), I (3, 1 [2]), J (2, 4 [2])
015: Auto Visor Project	B (5), E (X), F (X), H (X), I (4), J (X),	D (4, 5), L (5, 4)	A (2, 4 [1]), C (3, 5 [2]), G (2+, 5- [1]), K (X, 3 [1])
016: Building Better Stroller	C (2), D (1), I (3),	B (4, 3), G (3, 4), H (2, 3), K (2-, 3+)	A (2+, 4 [4-]), E (1, 3 [1+]), F (1, 3- [1-]), J (1+, 4 [1+]), L (2, 4- [1+])

017: 2013-Ultimate Mobility Aid	B (2), D (2), F (0), K (1)	A (1, 2), C (2, 1), E (0, 1), I (1, 2),	G (0, 2 [0]), H (1, 3 [3]), J (0, 2 [1]), L (2, 4 [3])
018: Perk Pad	A (1), B (3), C (3), D (5), E (1), I (3), J (0), L (0)	F (2, 3), H (3, 2), K (1, 0)	G 4, 2 [4-])
019: Firearm Safety	A (2), D (0), E (1), G (2), H (1), I (2), L (3)	B (4, 3), C (3, 2), J (2, 1), K (2, 3)	F (3, 1 [1])
020: 2013-Airless Paint Overspray	B (2), C (2), F (1), G (2), J (1), L (1)	A (1, 2-), D (1, 0), E (1, 0), I (1, 2), K (1, 0)	H (3, 1 [2'])
021: Portable Vital Monitoring System	D (3), G (X), J (X), K (1), L (X)	B (4, 5), C (3, 4), E (0, 1-), F (1, 2), H (4, 5), I (3, 4),	A (3, 5 [3-])
022: Sustainable Power	A (1), B (1), D (1), E (X), G (X), H (X), I (X), J (X) K (1)	F (2, 1)	C (2, 0, 1)
023:2013-Soft Close Door	B (3), F (2), J (3), K (0)	A (3, 4), C (2, 1), E (1, 0), H (2+, 3-), I (2, 3), L (1, 2)	D (3, 1 [1]), G (2, 4 [2])
024:2013-Forklift Safety	B (4), D (5), E (5), F (5), I (2), K (5), L (5)	A (4, 5), C (4, 5), J (4, 5)	G (3, 5 [5]), H (3, 1 [1+])
025: 2013-Cooled Automotive Intake	B (2), C (1), F (1), L (2)	A (1, 2), D (1, 2), E (0, 1), G (2-, 1), H (1, 2), I (1, 2), J (0, 1),	K (1, 3 [2])

026: 2013-Rotator Cuff Injuries (Shoulder Injury)	C (1), H (1), I (1), J (1),	A (1, 2), B (2, 1), D (2-, 1+), E (1, 0), F (1, 2), G (2, 1), K (3, 2+), L (2+, 1)	
027: Quantitative Solutions for Energy	A (1), D (2), E (X), F (2), G (X), H (X), I (X), J (X), K (1), L (X)	B (1+, 2),	C (1, 3+ [3])
028: 2013-Grilling Safety	B (2), C (2), G (3)	A (3-, 2), H (1, 2+), I (2, 3-)	D (0, 2 [1+]), E (l, X [1-]), F (0, 3- [0]), J (0, 2 [1-]), K (1, 4- [1-]), L (2, 4 [2])
029: 2013-Colorblind Driving	B (2), D (2), J (0), K (0), L (1)	C (1, 0), E (1-, 0), H (1, 2),	A (1, 3 [2-]), F (1, 4 [2]), G (2, 4 [2]), I (1, 3 [2])
030: Prevention of Dust Explosions	A (1), G (3), I (1), L (1)	E (1+, 2), F (1, 2), J (0, 1), K (1, 2)	B (0, 2 [1]), C (1, 5 [2]), D (1, 3 [0]), H (1, 3 [1+])
031: Enlighten Lock	L (2)	B (3, 4-), C (1, 2+), K (0, 1)	A (1, 3 [2]), D (2, 4 [2-]), E (1, 3 [2-), F (0, 4 [2+]), G (1, 3+ [0]), H (1, 3+ [2]), J (1-, 3 [3-])
032: 2013-Silverbacks	A (1), B (2), D (2), E (1), H (0), I (0), J (0), K (0), L (3)	C (2-, 3-), F (2, 1-), G (1, 2+)	
033:Reach a Tool	B (2+), E (1), F (1), H (1), I (1), J (1)	A (2, 1), G (1, 2), L (0, 1)	C (3, 1 [3]), D (4-, 2 [3]), K (0, 2- [0])

034: Ergo Corture Project	A (5), B (5), C (5), E (X), F (5), G (0), H (3), J (X)	D (5, 4), I (5, 4), K (0, 1), L (4, 3)	
035: 2013-Creo	A (2), B (2), E (1), H (2), I (2), J (0),	D (2, 3-), K (2-, 1), L (0, 1)	C (1, 3- [1-]), F (0, 3 [0]), G (1, 3 [4])
036: Audio Armor	A (2), D (1), E (1), F (1), J (0), K (0), L (1)	C (1+, 0), G (1, 2-), H (3, 2+), I (3, 2)	B (3-, 1 [4])
037: 2013-Dog Restraint	A (3), C (1), E (1), H (1), J (1), K (0)	B (2, 1+), D (3, 2-), F (1, 0), G (0, 1-), I (1, 2)	L (0, 2 [1])
038: Accidental Firearm Discharge	L (3)	B (4-, 3), C (1+, 2), D (3, 2+), E (1, 0), G (2, 1), H (3+, 2-), I (3, 2), J (1, 2-), K (1, 2)	A (1, 4 [4-]), F (2, 0 [1])
039: Modular Video Control	C (1), J (0), L (X)	A (2, 3), B (1, 2), G (3, 2+), I (0, 1), K (0, 1)	D (1, 3 [1]), E (0, 2+ [1]), F (1, 3- [1]), H (1, 3- [0])
040: 2013-Self-Cooling Pillow	A (2), B (2), D (2), H (1), I (3)	C (1+, 2), E (1-, 0), J (2+, 1+)	F (3-, 0 [1+]), G (3, 1 [1]), K (1, 4- [2]), L (1, 3+ [2])
041: Dual Shoulder Camera Mount	A (2), E (1), F (0), H (0), J (0), K (0), L (X)	B (3, 2), C (3, 2-), D (1, 2), I (2-, 1)	G (1-, 3 [0])
042: Bicycle Helmet Project	D (5), H (X), J (X), K (5), L (X)	B (4+, 5), F (4, 5), G (4+, 5), I (4, 5)	A (2+, 5 [5]), E (2, 5 [3])

043: Easy Gardening	D (2-)	A (2, 3), B (4-, 3), C (2+, 3-), E (2, 3-), F (3, 2), G (1-, 0), H (2-, 1), I (3+, 2), J (4-, 3+), L (3+, 2)	K (5, 2 [3])
044: Rear End Collision Avoidance	D (0), I (0), J (0), K (0)	C (0, 1), G (0, 1), H (0, 1), L (0, 1)	A (0, 4+ [5-]), B (0, 3+ [5]), E (0, 3+ [5]), F (0, 3- [5])
045: Solar Power	E (X), G (X), H (X), I (X), J (X), L (X)	B (0, 1), C (1, 2), F (1, 2)	A (0, 3- [2]), D (0, 4- [3+]), K (1, 3 [0])

Key:

[ ] Possible entries to complete Anchor Set

[ ] Selected in 2013 for Anchor Set; annotated but not yet posted; all were either in exact or nearly exact agreement overall (2013 and 2015)

[ ] Exact agreement entries (100% agreement for portfolios scored in 2013 AND 2015).

[ ] "Close calls" (at least 75% exact agreement, no discrepant agreement. For portfolios scored in 2013 AND 2015)

X = entry left blank

NOTE: Entries with exact agreement scores for new (2015) portfolios may be suitable for instructional and provisional training purposes

Appendix G. EDPPSR Anchor Samples as of May 2015

Element	0	1	2	3	4	5
A	*Laundering Socks(2009)*	Car Lockout	Snowmobile	Snow Clear LED	*Forklift Safety (4+)*	*Ergo Corture*
B	Art. Blood Vessel	Car Lockout	Snow Clear LED	Tree Ice Accum.	*Forklift Safety* (4+)	*Ergo Corture*
C	Posture Correction	Snow Clear LED	Stylus Relief	*Lawn Mower Kick Starter*	*Crutch Beverage Holder*	*Forklift Safety*
D	Bicycle Tire Pres.	Emergency Crutch	Posture Correction	Stylus Relief	Thermobile	*Forklift Safety*
E	Bicycle Tire Pres.	Door Speed Control	*Crutch Beverage Holder*	Pool Chem. Delivery		*Forklift Safety*
F	Rain Detection	Posture Correction	Bicycle Tire Pres.	*E-Waste*	Ladder Accident Prevention	*Ergo Corture*

G	**Tree Ice Accum.**	**Car Window Roll-up**	**Posture Correction**	**Reinventing Life Jacket**	***Crutch Beverage Holder***	
H	**Snow Obstr.**	**Reinventing Life Jacket**	**RFID Lockout prevention**	***Avengineering***		
I	**Snow Removal**	**Tree Ice Accum.**	**Reinventing Life Jacket**	**Ladder Accident Prevention**	***Auto Visor Project***	
J	**Posture Correction**	**Safe Clean Store**	**Stylus Relief**	**Door Speed Control**	***Check Engine Light***	
K	**Posture Correction**	**Stylus Relief**	**Safe Clean Store**	**Door Speed Control**	**Extra Lure Safe**	***Forklift Safety* (5-)**
L	**Emergency Crutch**	**Posture Correction**	**Safe Clean Store**	**Stylus Relief**	***E-Waste***	

Key:

[ ]) Anchor selected after 2015 workshop or selected after 2013 workshop and confirmed in 2015; all still to be annotated and posted to the Innovation Portal

[ ] No suitable entry available yet to serve as anchor sample