Applying US EPA sustainability criteria to capstone design

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Abstract

The engineering department uses a unique two-year long capstone engineering project to provide an opportunity for experiential based application of fundamental engineering sciences and practice analyzing sustainable design principles. Recently the course adopted the United States Environmental Protection Agency (EPA) P3 proposal template for a semester report and also used the EPA P3 evaluation criteria to develop a detailed rubric for evaluating student success in implementing sustainability criteria into their design projects. The EPA P3 program is "a unique college competition for designing solutions for a sustainable future stands for People, Prosperity and the Planet". Prior to implementing the P3 based template and rubric, typical project claimed sustainability (talked-the-talk), but had great difficulty applying science and engineering principles to provide evidence of sustainability (walk-the-walk). After applying the rubric students reported that their understanding of the application of sustainable design principles was enhanced. Students also stated that the detailed rubric significantly enhanced their technical writing and helped them focus on the importance of describing and interpreting evidence in their reports. This paper will describe how the P3 criteria were used to develop the report template and provide an example template showing the progression in writing.

Keywords

Capstone design, sustainability, technical writing

Introduction

Engineering was introduced for the first time at James Madison University (JMU) for students entering college in the Fall of 2008. The mission of the new program stated "James Madison University's engineering graduates will improve the sustainability of our world by participating in projects in which they analyze problems and design solutions in the context of technical, economic, environmental and social impacts."

Sustainability is important in manufacturing, construction, planning and design. Alleby *et. al*. state that: "Sustainable engineering is a conceptual and practical challenge to all engineering disciplines.[1]" Environmental engineering and chemical engineering textbooks may cover some basics concepts of sustainability, but the extent and breadth of knowledge is insufficient to meet the multifaceted demand associated with engineering sustainable processes and products.[2]

Crittenden suggests that sustainable solutions include the following important elements/steps: (a) translating and understanding societal needs into engineering solutions such as infrastructures, products, practices, and processes; (b) explaining to society the long-term consequences of these engineering solutions; and (c) educating the next generation of scientists and engineers to acquire

both the depth and breadth of skills necessary to address the important physical and behavioral science elements of environmental problems and to develop and use integrative analysis methods to identify and design sustainable products and systems.[3]

The United State Environmental Protection Agency (EPA) has also incorporated sustainability principles into its mission. Sustainability was defined by Executive Order 13514 "to create and maintain conditions, under which humans and nature exist in productive harmony, that permit fulfilling the social, economic and other requirements of present and future generations".[4]

In 2002, the EPA began the People, Prosperity and the Planet (P3) grant program to fund sustainable design and engineering projects. The EPA P3 program is "a unique college competition for designing solutions for a sustainable future stands for People, Prosperity and the Planet". Through this EPA program students define and design environmental solutions to complex problems. The EPA P3 program includes projects that address problems associated with "water, energy, agriculture, built environment, and materials and chemicals" for both the "developed or developing" world. As a part of this EPA program, college students design environmental solutions to relatively small scope projects. Since 2002 nearly 600 projects have been funded. The thirteen-year history of the program has allowed for the development of detailed proposal, reporting and evaluation criteria. The EPA P3 program considers water, energy, agriculture, built environment, and materials and chemicals related projects. This range of projects closely matches many of the capstone design projects that have been completed at JMU, as shown in Figure 1.

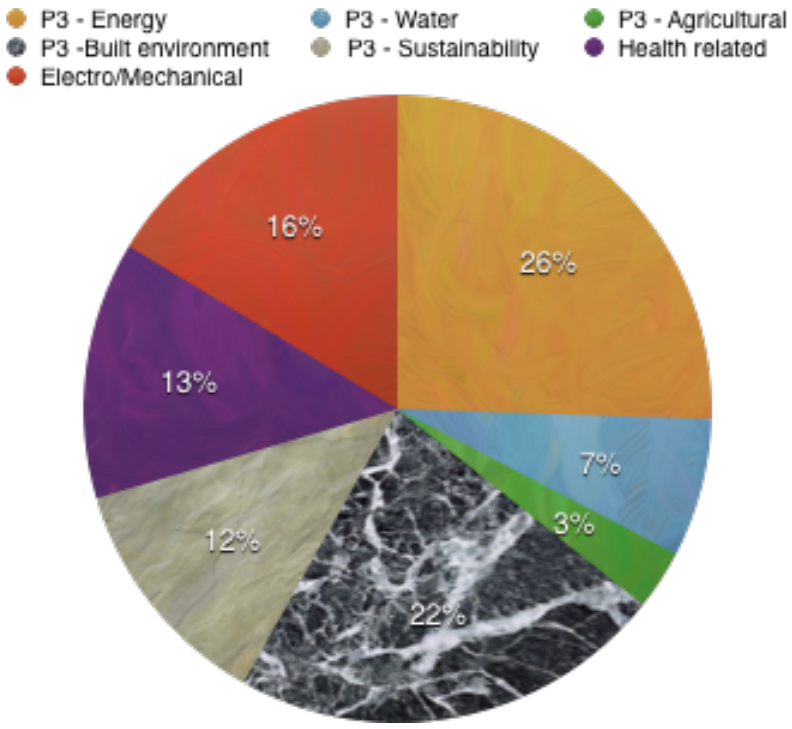


Figure 1: Alignment of JMU engineering capstone projects with EPA P3 project categories from 2010 to 2015.

The engineering program has developed a two-year sequence of sustainable design-focused courses.[5] The two-course sequence was developed to address the original mission statement of the department:

"Department of Engineering graduates will improve the sustainability of our world by analyzing problems and designing solutions in the context of technical, economic, environmental, and social impacts."

The third course in the two-year sequence, ENGR 431: Engineering Design V has objectives and goals that most closely align with the Phase 1 EPA P3 program goals. The ENGR 431 course is the fifth in the six-course 16-credit developmental design sequence. This project-based course provides instruction in collaborative project management, holistic design evaluation, social and community sustainability, design testing and marketing, principles of design marketing and accounting, problem solving analysis, software tools, project management and testing and analysis of prototypes. The JMU curriculum includes a one-year sophomore design based course, in which students built a bicycle for a specific clients needs. This consists of two-credit ENGR 231: Engineering Design I and two-credit ENGR 232: Engineering Design II. JMU students begin their two-year long capstone project in the third year of the program in three-credit ENGR 331: Engineering Design III and three-credit ENGR 332: Engineering Design IV. Students choose a design topic, study design approaches and conduct a literature review as outcomes associated with ENGR 331 and 332. A prerequisite grade of "C-" or better grade (indicating a 70 percent or better grade) in the previous design course (ENGR 332) is required. The course objectives and alignment to ABET criteria are listed in Table 1.

Table 1. Expected outcomes and related ABET criteria for sustainability-focused design course ENGR 431.

Course Outcomes Upon successful completion of this course, the student will be able to:	**ABET Outcomes**
1. Apply advanced design thinking, principles, and tools	C
2. Demonstrate holistic and critical evaluation of design artifacts	C
3. Demonstrate competence in customizing a design process to meet the needs of the project and the team	C, D
4. Understand fundamental principles of psychology of design and human factors decisions	C, J, F
5. Apply reliability analysis in design decision making	C, A, E
6. Demonstrate analytical modeling in design decision making	A, E
7. Work effectively on a collaborative design project	D
8. Demonstrate individual and collaborative technical writing skills	G
9. Demonstrate individual and collaborative technical presentation skills	G
10. Develop a professional career development plan and artifacts	I

In previous iterations of the course, students had difficulty utilizing the textbook based report format. In addition, students and some project reviewers suggested the report was inconsistent with reporting practices in some disciplines. A re-design faculty and student workshop was held to identify high-priority improvements to the design course as offered from 2010 through 2014. The suggestions that had the most student and faculty support included:

- Using a module based approach to class content
- External validation of project quality and clearer articulation of excellence
- Decreased entanglement between textbook problems and project goals

Several steps were taken to make the course more modular, by adding more diverse group of faculty instructors and creating smaller course sections. This also allowed the instructors to "personalize" each section thereby decreasing the perception of conflicting course goals. The opportunity to focus on clearer articulation of excellence, external validation and improving the report format lead to an investigation of alternative report formats that were representative of professional practice and provided addition guidance.

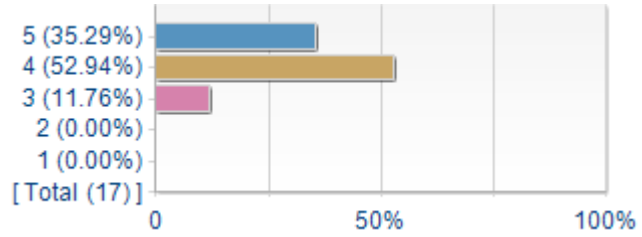
Modular approach to design

Students were able to select completion of two of four options on-line modules that related to some of their capstone projects and the EPA P3 criteria. These modules included online reading assignments, on-line video lectures, and on-line multi-media presentations from instructor selected web-based resources that were located on a Canvas™ course website. Students were required to complete online assignments and homework problems to demonstrate competency in these areas. Applications of the module concepts into their final project report was encouraged but not required. The available modules consisted of the following topics:

- Design for Energy Sustainability
- Industrial Ecology
- Life Cycle Assessment
- Green Building and Low Impact Development (LID)

Student feedback was collected to provide feedback on how the EPA report format and rubric were received and utilized by the students in the pilot section.The effectiveness of the course was evaluated with mixed methods, using student survey responses on a 5-point Likert-type scale and open-ended student responses. The students were asked to evaluate how valuable each module was in terms of contributing to the course outcomes and project objects. The responses are shown in Figures 2 to 6.

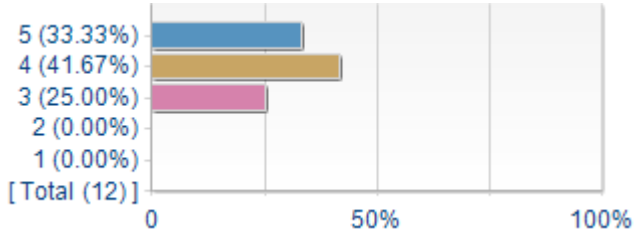
The information on the Canvas site was useful



Statistics	Value
Response Count	17
Mean	4.24
Median	4.00
Mode	4
Standard Deviation	+/-0.66
Population Standard Deviation	+/-0.64

Figure 2: Student feedback on the overall usefulness of the on-line modular approach to the optional design topics.

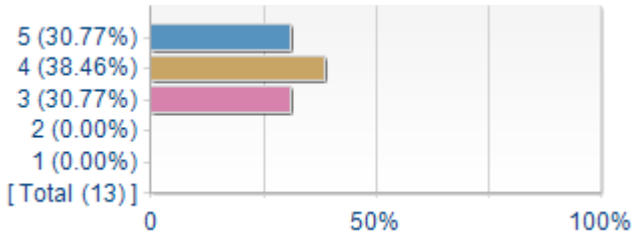
The module on Design for Energy Sustainability was valuable



Statistics	Value
Response Count	12
Mean	4.08
Median	4.00
Mode	4
Standard Deviation	+/-0.79
Population Standard Deviation	+/-0.76

Figure 3: Student feedback on the effectiveness of the Design for Energy Sustainability module with 5 indicating the module was extremely valuable and 1 indicating the module was not at all valuable.

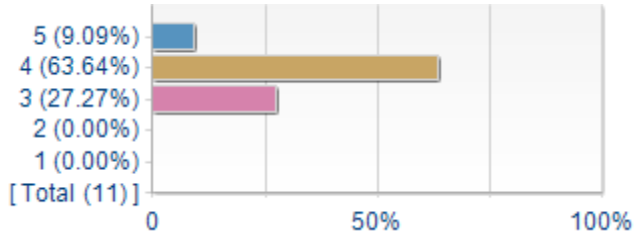
The module on Industrial Ecology was valuable



Statistics	Value
Response Count	13
Mean	4.00
Median	4.00
Mode	4
Standard Deviation	+/-0.82
Population Standard Deviation	+/-0.78

Figure 4: Student feedback on the effectiveness of the Industrial Ecology module with 5 indicating the module was extremely valuable and 1 indicating the module was not at all valuable.

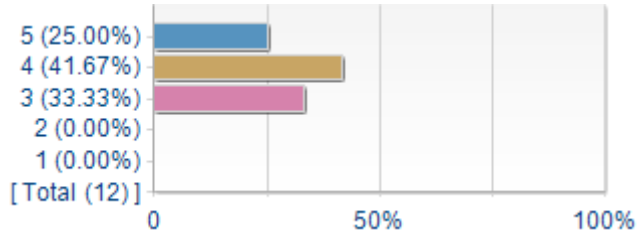
The module on Life Cycle Assessment was valuable



Statistics	Value
Response Count	11
Mean	3.82
Median	4.00
Mode	4
Standard Deviation	+/-0.60
Population Standard Deviation	+/-0.57

Figure 5: Student feedback on the effectiveness of the Life Cycle Assessment module with 5 indicating the module was extremely valuable and 1 indicating the module was not at all valuable.

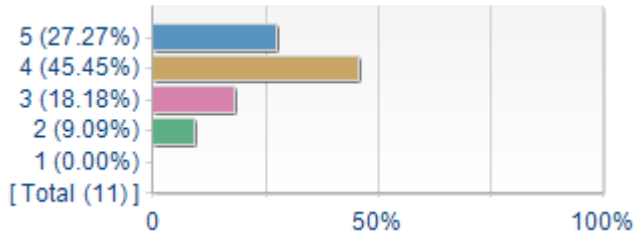
The module on Green Building and LID was valuable



Statistics	Value
Response Count	12
Mean	3.92
Median	4.00
Mode	4
Standard Deviation	+/-0.79
Population Standard Deviation	+/-0.76

Figure 6: Student feedback on the effectiveness of the Green Building and LID module with 5 indicating the module was extremely valuable and 1 indicating the module was not at all valuable.

The module on current issues in sustainability innovation was valuable



Statistics	Value
Response Count	11
Mean	3.91
Median	4.00
Mode	4
Standard Deviation	+/-0.94
Population Standard Deviation	+/-0.90

Figure 7: Student feedback on the effectiveness of the Design for Energy Sustainability module with 5 indicating the module was extremely valuable and 1 indicating the module was not at all valuable.

During the fall semester of 2015 a pilot section of the course adopted the reporting framework of the EPA P3 program. The adoption of this new format required student to start with a “clean-slate” for their report, instead of adding onto previous work, which had been difficult to

appropriately grade, as the report grew over the four semester time period during which students worked on the projects. In addition, course objectives and the EPA P3 criteria were utilized to create a detailed writing rubric (Shown in the appendix of this report) for students. Furthermore the rubric was used in a competency-based fashion. Students were required to submit two drafts during the semester the first draft was submitted to the instructor and feedback was provided based upon the rubric. The rubric provided clear guidance as to how the students described their project in terms of the well-defined EPA P3 criteria. Students utilized content from two semesters of sustainable engineering courses (ENGR 411 and ENGR 412) that are described elsewhere to address the P3 criteria.[5, 6] Subsequent submissions were evaluated using the same rubric, but by a diverse committee of the student's peer group to identify remaining areas of concern or lack of clarity. Only the final submission was factored into the student's term-grade, so that each time the student teams could revise and improve their report without any threat to their grade for the course.

Open-ended Student Responses included the following information about the course format:

"This semester because of this class and ENGR 314 I finally understand the purpose of a design report."

"Structure of the classroom, contributed greatly to capstone progress"

"I liked the modules idea, that worked well"

I liked best about the course:

> "the rubric for the final paper"
>
> "The set rubric of what was expected this semester."
>
> "The diversity of the capstone projects and watching them evolve helped identify a variety of career opportunities. The different capstone projects and how they were completed related course topics to engineering issues. Also, there were many professional engineering issues and solutions that engineers have come up with presented in the modules."

The evidence suggested that the students appreciated and utilized the on-line modules for the course. This allowed subject matter to be geared more specifically to each project topic. Also, The adoption of the "real-world" EPA P3 proposal and report format appeared to help some students understand the significance and value associated with both their written communication and sustainability concepts.. Students and project evaluators also reported that the P3-based rubric helped the students with their technical writing. The rubric was used in a competency-based tool, whereby students submitted report drafts and received rubric-based feedback from the instructor and student peer-reviewers two to four times throughout the semester. Only the final submittal was used in calculating the student's course grade. Thus students could see where weaknesses were in their reporting, address those weaknesses, and see the progression (from left to right) of their writing and reporting skills on the rubric.

Summary

To date, the instructor is pleased with the outcomes demonstrated by adopting the US EPA P3 report format. Anecdotal evidence, observations and students comments suggest student like on-line modular options directed towards their specific project and/or interests. Students also appreciated the "real-world" report format. Since the EPA P3 project closely matches the capstone project goals, students report having a clearer understanding of expectations and feel they have been provided better direction by using the syllabus and peer-review to improve the clarity of their reports.

References

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Appendix

Table 2: P3 Based Final Report Rubric:

	Project:		ENGR 432.2 CAPSTONE PROJECT REPORT EVALUATION - *Circle statement or place a check in the appropriate box*					
			0	Low	Medium	High	NA	Possible Pts
1	**Project Title**	**20**	Missing or not understandable.	Does not accurate portray the scope or nature of the project, is misleading to the reader.	Parts of High and Low	Accurately reflects the project goals and scope. Is sufficient to understand the nature of the project.	N/A	**4**
2	**Title Page**	**4**	Missing or not understandable.	Missing more than one item from the checklist	Parts of High and Low	All information is complete. Signatures are real and authentic. Capstone advisors names are listed and correct.	N/A	**2**
3	**Key Contacts**	**4**	Missing or not understandable.	Incorrectly formatted or incomplete	Parts of High and Low	Complete, accurate and correctly formatted	N/A	**2**
4	**Contents**	**4**	Missing or not understandable.	Incorrectly formatted or incomplete	Parts of High and Low	Complete, accurate and correctly formatted	N/A	**2**
	Abstract	**4**						
5	**Funding Opportunity Number and Research Areas**	**4**	Missing or not understandable.	Incorrectly formatted or incomplete	Parts of High and Low	Complete, accurate and correctly formatted	N/A	**2**
6	**Project Title**	**4**	Missing or not understandable.	Incorrectly formatted or incomplete	Parts of High and Low	Complete, accurate and correctly formatted	N/A	**2**
7	**Principal Investigator**	**4**	Missing or not understandable.	Incorrectly formatted or incomplete	Parts of High and Low	Complete, accurate and correctly formatted	N/A	**2**
8	**Student Team**	**4**	Missing or not understandable.	Incorrectly formatted or incomplete	Parts of High and Low	Complete, accurate and correctly formatted	N/A	**2**
9	**institution(s)**	**4**	Missing or not understandable.	Incorrectly formatted or incomplete	Parts of High and Low	Complete, accurate and correctly formatted	N/A	**2**
10	**Student Represented Departments and Institutions**	**4**	Missing or not understandable.	Incorrectly formatted or incomplete	Parts of High and Low	Complete, accurate and correctly formatted	N/A	**2**
11	**Project Period and Location**	**4**	Missing or not understandable.	Incorrectly formatted or incomplete	Parts of High and Low	Complete, accurate and correctly formatted	N/A	**2**
12	**Proposed Project Cost (not to exceed $15,000)**	**4**	Missing or not understandable.	Incorrectly formatted or incomplete	Parts of High and Low	Complete, accurate and correctly formatted	N/A	**2**
13	**Total Project Amount**	**4**	Missing or not understandable.	Incorrectly formatted or incomplete	Parts of High and Low	Complete, accurate and correctly formatted	N/A	**2**
14	**Objective**	**40**	Missing or not understandable.	Project objectives are not clearly defined or are inappropriate to the available timescale and budget	Parts of High and Low	The project is sound, feasible, and appropriate to address the challenge identified.	N/A	**20**
15	**Description**	**40**	Missing or not understandable.	Project approach is not clearly defined or is inappropriate to the available timescale and budget.	Parts of High and Low	A quantitative and qualitative evaluation method is proposed to assess the project goals (esp. economic, environmental, social and technical design elements/factors.)	N/A	**20**
16	**Results**	**40**	Missing or not understandable.	The expected results are not clearly identified or do not address any of the three aspect of sustainability (economic, environmental, social or people, planet, prosperity)	Parts of High and Low	Identify the expected outputs/outcomes of the project and provide a description of the strategy for measuring results, evaluation and demonstration.	N/A	**20**
17	**Contribution to Pollution prevention or Control**	**20**	Statutory authorities and codes are missing or incorrectly identified	Statutory authorities and codes are incomplete	Statutory authorities and codes are correctly identified	Statutory authorities and codes are correctly and clearly related to the project goals and objectives	N/A	**20**
18	**Supplemental Keywords**	**4**	Missing or not understandable.	Incorrectly formatted or incomplete	Parts of High and Low	Complete, accurate and correctly formatted	N/A	**4**

	Project Plan: Project Design							
19	**Goals**	**20**	Missing or not understandable.	Missing more than half the items from the checklist, is too verbose, and does not speak to the project.	Parts of High and Low	Statement the covers all the items, is brief and conveys the essence of the project. Will help the PM manage the project.	N/A	**12**
20	**Objectives**	**20**	Missing	Missing statutory requirements, innovative concepts, scientific soundness and discussing trade-offs in the proposed design approach	Parts of High and Low	Relates statutory requirements, identified innovative concepts, addresses the feasibility of the project by demonstrating scientific soundness and discussing trade-offs in the proposed design approach	N/A	**12**
21	**Stakeholder Identification/ Impact/Strategy**	**4**	Missing	Missing many stakeholders, stakeholder analysis was not done, and not related to what may influence the project.	Parts of High and Low	Stakeholder analysis done with the stakeholder, what they can offer, and what they expect listed. This is related to how it may influence the project. Strategy to manage the stakeholders is convincing.	N/A	**12**
	Project Plan: Challenge Definition							
22	**Technical Challenges**	**20**	Missing	Incompletely identifies the technical challenge of the projects and does not relates the challenge in terms that are relevant, significant and related to sustainability	Parts of High and Low	Identifies the technical challenge of the projects and relates the challenge in terms that are relevant, significant and related to sustainability	N/A	**20**
	Literature review							
23	**Familiarity**	**12**	Description of relevant literature seriously lacking, no analysis of relevant literature	Limited description of relevant literature, no analysis of relevant literature evident	Adequate description and analysis of relevant literature	Comprehensive description and analysis of relevant literature	N/A	**8**
24	**Credibility**	**12**	Credibility not evaluated	Elements of credibility considered but misapplied	Credibility evaluated and linked to proposed work	Credibility evaluated and integrated into proposed work	N/A	**8**
25	**Analysis, synthesis and application**	**0**	Relevant literature not applied to proposed project work	Some literature used but not applied to proposed project work	Literature analyzed, synthesized and applied to proposed project work	Literature rigorously analyzed, synthesized and applied to proposed project work	N/A	**12**
26	**Communicates understanding**	**12**	Research question, research gap and research significance not communicated	Limited communication of research question, research gap and research significance	Adequate communication of research question, research gap and research significance	Clear and comprehensive communication of research question, research gap and research significance	N/A	**12**
	Project Plan: Relationship of Challenge to Sustainability (People, Prosperity and the Planet)							
27	**People**	**20**	Missing or not understandable.	Missing more than half the items from the checklist, is too verbose, and does not speak to the project.	Parts of High and Low	Explain how you plan to engage with intended end users. Describe how the proposed environmental and economic outcomes could benefit the intended users and society more generally. Discuss how the project/design will reduce negative or increase positive impacts on human health.	N/A	**12**
28	**Prosperity**	**20**	Missing or not understandable.	Missing more than half the items from the checklist, is too verbose, and does not speak to the project.	Parts of High and Low	Identify short- and long-term costs associated with the project/design, including potential implementation and maintenance costs. Describe the potential economic benefits of the project/design, including market share, if appropriate.	N/A	**12**

29	**Planet**	**20**	Missing or not understandable.	Missing more than half the items from the checklist, is too verbose, and does not speak to the project.	Parts of High and Low	Discuss how the project/design will reduce negative or increase positive impacts on the environment, diminish resource consumption, and/or directly benefit the environment over its full lifecycle. Address the impacts of the project/design on the local environment and ensure that it will not shift negative environmental impacts to another locality or media (e.g., air, water, land).	N/A	**12**
	Project Plan: Educational and Interdisciplinary aspects of your proposed project							
30	**Educational Benefits**	**12**	Missing or not understandable.	Missing more than half the items from the checklist, is too verbose, and does not speak to the project.	Parts of High and Low	Identifies and describes how the team will encourage sustainability or implementation among participants, institutions, and or surrounding communities	N/A	**4**
31	**Interdisciplinary Aspects**	**4**	Missing or not understandable.	Missing more than half the items from the checklist, is too verbose, and does not speak to the project.	Parts of High and Low	Clearly identifies the interdisciplinary aspects of the project	N/A	**4**
	Results (outputs/outcomes), Evaluation and Demonstration							
32	**Style, structure and editing**	**12**	The work is not written in an appropriate format and contains numerous style and editing problems.	The work includes all elements of a report but contains distracting style and editing problems.	The structure and style are appropriate with few errors in language.	The work is well structured with appropriate style and is free of errors in language.	N/A	**12**
33	**Organization**	**12**	Poor organization of information; project implications unclear	Information and implications misinterpreted or very difficult to discern	Information and implications are there, but require some effort to discern the implications for the project. Appropriate visual elements, such as Tables and Figures, are used.	Information is well organized with insights and implications for project decisions clearly defined. Appropriate visual elements, such as Tables and Figures, are used.	N/A	**12**
34	**Parameters**	**20**	Missing or not understandable.	Some parameters are missing or the system is over-constrained. Values are unreferenced or unrealistic.	Parts of High and Low	All relevant parameters are identified, the relationship to the project explained and realistic values (range) reported	N/A	**20**
35	**Relationships/ Equations**	**20**	Missing or not understandable.	Some engineering science equations are identified and variables have been partially related to project parameters. Important governing equations are missing or incorrectly interpreted.	Some engineering science equations are identified and variables have been partially related to project parameters.	Relevant engineering science equations are identified and variables have been correctly related to project parameters	N/A	**20**
36	**Analytical model**	**4**	Missing or not understandable.	Equations are missing. The data is not presented in an appropriate format using tables and figures.	Equations a have been partially solved and related to the project objectives. The data is presented, but tables and figures are difficult to interpret.	Equations a have been solved and related to the project objectives. The data is presented in an appropriate format using tables and figures.	N/A	**40**
37	**Results**	**8**	Missing or not understandable.	Results are missing. Evidence is inconclusive. Decisions are not supported and explained.	Results are reported but not related to project objectives. Evidence is inconclusive. Decisions are partially supported and explained.	Results are reported and related to project objectives based upon reported evidence. Evidence is supporting of all design decisions.	N/A	**40**

	Testing and Refinement							
38	**Conditions**	**12**	Missing or not understandable.	Experimental conditions are not adequately described and relation to the problem statement is not explicit	Parts of High and Low	Experimental conditions and relation to the problem statement are concisely described and complete	N/A	**16**
39	**Controls**	**12**	Missing or not understandable.	Experimental controls are not completely identified and poorly explained.	Parts of High and Low	Experimental controls are completely identified and concisely explained.	N/A	**20**
40	**Variables**	**12**	Missing or not understandable.	Experimental variables are not completely identified and poorly explained.	Parts of High and Low	Experimental variables are completely identified and concisely explained.	N/A	**20**
41	**Analysis**	**8**	Missing or not understandable.	Rationale for experimental protocol is unclear and tangentially related to objectives	Parts of High and Low	Experiments are explicitly related to design or equations	N/A	**40**
42	**Methods**	**12**	Missing or not understandable.	Methods have not been adequately documented, calibrated or verified	Parts of High and Low	Methods are well researched, documented with codes, with calibration and verification	N/A	**40**
43	**Limitations/interferences**	**12**	Missing or not understandable.	Methods limitations and interferences have not been adequately documented, calibrated or addressed	Parts of High and Low	Methods limitations and interferences are well researched and plans to calibrate and verify methods	N/A	**30**
44	**Variability**	**8**	Missing or not understandable.	Variability in data has not adequate been planned for.	Parts of High and Low	A statistically valid set of experimental protocols has been planned and clearly articulated	N/A	**30**
45	**Sample/testing plan**	**12**	Missing or not understandable.	The sampling plan is unclear. Significant elements are missing.	Parts of High and Low	The sampling/testing plan is in a tabular form that addresses an adequate number of replicates, accounts for variables and controls, and provided dates for the testing	N/A	**30**
	Detailed Design and Analysis							
46	**Presentation of analytical results (i.e. calculations)**	**80**	Missing or not understandable.	Equations are miss represented, variables are not identified	Equations are presented, variables are identified, solutions are presented, data is represented	Equations are presented, variables are identified, solutions are presented and correct, data is presented in a tabular and/or graphical format	N/A	**40**
47	**Presentation of empirical results (testing)**	**40**	Missing or not understandable.	Data is presented but interpretations are unclear, illustrations are present	Data is presented, data is interpreted, tabular, graphical or visual models are unclear, drawings are present	Data is presented, data is interpreted, error bars are presented or uncertainty is identified, tabular, graphical or visual models are presented, engineering drawings are present, dimensions are provided	N/A	**40**
48	**Link between results and literature**	**30**	Missing or not understandable.	The interpretation is not consistent with the data	The results are related to information in the literature. The interpretation is not consistent with the data and comparisons are discussed	The results of analytical and empirical tests are related to information in the literature, codes, or standards. The interpretation is consistent with the data and comparisons are correctly discussed in numerical detail	N/A	**40**
49	**Discussion of results and interpretation**	**30**	Missing or not understandable.	Conclusions are based on data, results are interpreted in the context of broader literature, sustainability criteria are numerically addressed.	Conclusions are based on data, results are interpreted in the context of broader literature, sustainability criteria are numerically addressed.	Conclusions are based on data, data is verifiable, data and conclusions are easily interpreted from report illustrations or tables, the discussion is concise and well written, results are interpreted in the context of broader literature, sustainability criteria are numerically addressed.	N/A	**40**
50	**Discussion of limitations and uncertainty**	**30**	Missing or not understandable.	limitations of the results are vaguely discussed	Uncertainty calculated, limitations of the results are presented in the broader context of the literature and implementation	Uncertainty is planned for in experimental design, uncertainty is calculated for appropriate variable, limitations of the results are presented in the broader context of the literature and implementation	N/A	**40**

	Project Schedule and Milestones							
	Team management							
51	**Communication Plan and Matrix**	**2**	Missing or not understandable.	Missing many stakeholders, communications are inappropriate, missing major events that require communications.	Parts of High and Low	All stakeholders are indicated with the appropriate amount of communication. Major events are indicated in plan. The plan will help manage the project.	N/A	**2**
52	**Responsibility Matrix**	**2**	Missing	More that one person responsible or no one indicated. Limited or no support shown. Tasks are missing.	Parts of High and Low	Matrix show clearly one person responsible for each task. Some support shown. Team names are used	N/A	**2**
	Project Management							
53	**Time, Cost, Performance trade-off Assessment**	**2**	Missing	Matrix format missing, items assigned to two categories, or some categories not assigned. No explanation why items were placed; no mention of customer.	Parts of High and Low	Matrix present with one item assigned for constrain, enhance, accept. Explanation for why this was chosen and customer approval discussed.	N/A	**2**
54	**WBS (MS Project Entry Table)**	**2**	Missing	Missing major parts of the project, not sufficiently broken down, is a mixture of deliverables, actions, or specifications. Requirements are listed.	Parts of High and Low	WBS has all major deliverables listed and these are broken down to reasonable sized work packages. The WBS will help the PM manage and plan the project properly.	N/A	**2**
55	**Network Diagram**	**2**	Missing or not understandable.	Weak general description of what a network diagram is, doesn't highlight details of this project, and will not lead to helping the project succeed. Discussion of critical path or sensitivity missing.	Parts of High and Low	Highlights the important parts of the network diagram in a way that will help the project be managed to success, discusses the critical path, and assesses the sensitivity of the project.	N/A	**2**
56	**Risk Assessment**	**2**	Missing	Evidence of no quality thought going into the determination of risks, they are trivial and incomplete, Likelihood, impact, or detection difficulty are unreasonable and when is inappropriate.	Parts of High and Low	Reasonable number and realistic non-trivial risks identified, proper likelihood, impact, and detection difficulty assigned. The proper time of risk event shown.	N/A	**2**
57	**Risk Response Matrix**	**2**	Missing	Items misplace on graph from Risk Assessment	Parts of High and Low	Items properly place on graph from Risk Assessment.	N/A	**2**
58	**Response Severity Matrix**	**2**	Missing	Risk missing on the matrix from Risk Assessment, contingencies are unrealistic, trigger is misplaced, or no one from team listed as responsible.	Parts of High and Low	All risk events have a realistic contingency plan, the trigger is properly listed, and the responsible person from the team (not the advisor) is indicated.	N/A	**2**
59	**Risk Plan**	**2**	Missing or not understandable.	Weak general description of what a risk planning is, doesn't highlight details of this project, and will not lead to helping the project succeed. No evidence of what if planning.	Parts of High and Low	Highlights the important parts of the risk planning in a way that will help the project be managed to success, shows that the team is conducting what if drills.	N/A	**2**
	Status							
62	**Gantt Chart**	**8**	Missing	Hard to understand, does not represent the project well, axes are confusing or missing, and the estimates seem inaccurate.	Parts of High and Low	Gives a good overview of the project, time axis dates make sense, activities are listed, and estimates of activities make sense.	N/A	**2**
63	**Resource Allocation**	**2**	Missing or not understandable.	Weak general description of what a resource allocation is, doesn't highlight details of this project, and will not lead to helping the project succeed.	Parts of High and Low	Highlights the important parts of the resource allocation in a way that will help the project be managed to success, potential needs for more resources discussed.	N/A	**2**

	Conclusions and Recommendations							
65	**Conclusions**	**40**	Missing or not understandable.	Statements are somewhat supported by evidence. Addresses some aspects of sustainability qualitatively.	Parts of High and Low	Concise statements are supported by clear evidence within the report. Address aspects of sustainability quantitatively.	N/A	**40**
66	**Recommendations**	**20**	Missing or not understandable.	Statements are somewhat supported by evidence. Addresses some aspects of sustainability qualitatively.	Parts of High and Low	Concise statements are supported by clear evidence within the report. Address aspects of sustainability quantitatively.	N/A	**20**
	References							
67	**Type**	**12**	<50% form peer-reviewed sources	>50% from peer reviewed sources	>60% from peer-reviewed sources	>80% from peer reviewed sources (textbooks, journals, searchable government documentation)	N/A	**12**
68	**Presentation**	**4**	Missing or not understandable.	Some information sources are not documented.	All information is cited in text, and some information sources, such as information obtained from the Internet, are not correctly documented.	All information is cited in text, and the sources are correctly documented so that follow-up to the original sources is straightforward.	N/A	**4**
	Appendix							
69	**Customer needs & specs**	**4**	Missing	Present	Present	Present and organized with concise description of relevancy		**2**
70	**product catalogs**	**4**	Missing	Present	Present	Present and organized with concise description of relevancy		**2**
71	**raw data tables**	**4**	Missing	Present	Present	Present and organized with concise description of relevancy		**15**
72	**supporting calculations**	**20**	Missing	Present	Present	Present and organized with concise description of relevancy		**20**
73	**derivations of equations**	**20**	Missing	Present	Present	Present and organized with concise description of relevancy		**15**
74	**secondary engineering drawings**	**20**	Missing	Present	Present	Present and organized with concise description of relevancy		**12**
75	**sketches from concept generation**	**2**	Missing	Present	Present	Present and organized with concise description of relevancy		**2**
76	**codes and standards**	**4**	Missing	Present	Present	Present and organized with concise description of relevancy		**2**
77	**bill of materials or cost estimates**	**4**	Missing	Present	Present	Present and organized with concise description of relevancy		**2**
78	**additional literature**	**4**	Missing	Present	Present	Present and organized with concise description of relevancy		**2**
79	**resumes**	**4**	Missing	Present	Present	Present and organized with concise description of relevancy		**2**
80	**code of conduct**	**4**	Missing	Present	Present	Present and organized with concise description of relevancy		**2**
81	**other**	**4**	Missing	Present	Present	Present and organized with concise description of relevancy		**2**

	TOTAL	0 %		
	Out of	800	All Possible Points	1000