Engineering Report: A Tool to Facilitate Learning for Real-World Problem Solving

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***Abstract*—Data from a design-based pilot study that applied Engineering Report team project in facilitating the development of problem solving skills in a real-world situation are reported. Pedagogies validated in Model Eliciting Activities (MEA) and instructions for solving ill-structured problems are applied to the design and the implementation of the Engineering Report project. Students' written work and oral presentations are reviewed, using developed rubrics. In general, students gained engineer experiences and skills in analyzing a hydroelectric system. However, uneven learning outcomes are observed. Students who embraced the learning opportunity and learned to articulate problem spaces displayed positive learning outcomes beyond expectations. Instructional interventions are necessary to support students who are not able to break boundaries imposed by accustomed traditional approaches.**

Keywords—open-ended problems; design-based research; reasoning; evidence; real-world problem solving

I. Introduction

Problem-centered learning in flipped engineering classrooms provides students with excellent opportunities to improve their problem solving skills by engaging a broad range of problems [1-4]. Students are presented with problems that are pertaining to content subjects to be learned through solution processes inside classrooms. Preparations for these learning activities include watching online video modules and reading relevant textbook chapters before coming to the class [5]. The reading assignment is posted in Moodle, an online teaching software, by the instructor and/or TA. For the past four years, problem-centered learning has been experimented and tested in a couple of engineering courses. The majority of the problems utilized in group problem solving activities are designed to explore the structure and organization of domain knowledge, which help students expand their content knowledge base. Although these problems are not open-ended, solution paths to these problems in general are not restricted and predicable. In the end-of-semester survey every year, most students reported positive learning experiences in group problem solving. Students ascribed improved learning to types of problems that were not overtly structured and that were real-world relevant [6].

"Engineering Report" has been assigned as a team project in the course of Electric Drives in which lectures are flipped. The project requires student teams to document engineer analysis and design for a real situation/case created by the course instructor. Although the case is selected and developed by the instructor, it is expected to inspire authentic learning based on pedagogies of solving open-ended problems [7]. "Engineering Report" is to help students develop skills for solving real-world problems while fostering engineering teamwork concept and strategy. It is also to promote engineering thinking for critically reviewed and creative solutions. Students are asked to complete the project with the allocation of three hours of work per team member, including both inside and outside class time. Students embraced the learning opportunity, and reported positive learning outcomes of significantly improved teamwork skills [8]. Many graduating seniors believed that the team project helped build confidence and readiness for their future job [6, 8]. However, they indicated that they were not able to associate the project with course content learning, and suggested that the missed connection somewhat hindered learning. Students also requested detailed feedback for the written report [6].

To address students' concerns and to improve their learning experience, the current study investigates ways in which the Engineering Report project facilitates the development of problem solving skills for real-world challenges. It examines the influence of instructional interventions through reviewing students' written report. It seeks methods that engage students in self-evaluation through peer interactions, which enable timely feedback. Results of this study will be used to enhance the integration of Engineering Report project into engineering courses.

II. Background

There are two main instructional goals for Engineering Report team project: (i) restating and promoting student understanding of instructional goals for the course, and (ii) placing the learned content in context, with meaning and purpose. The project is unlike the course of Writing-Across-the Curriculum (WAC) that focuses on "write to learn" [9]. Instructional pedagogies employed for the project are based on empirically validated learning models: Modeling Eliciting Activities (MEA), Solving Ill-Structured Problems, etc. [7, 10]. In the following, we describe key design principles for MEA and instructions for problem-solving (PS) of ill-structured problems, and explain how they are applied to our study.

A. Consistency and Complementary between Instructions for Modeling Eliciting Activites (MEA) and Solving Ill-Structured Problems

MEA inspire students to learn in activities of inventing and testing models that are framed as open-ended problems [10]. They challenge students to solve complex problems in real-world situations. Modeling-eliciting activities employ six essential principles that focus learning not only on knowledge construct and practical skill development, but also on building a strong sense of relevance, relating classroom learning to real-world situations. Given the emphasis of MEA design guidelines, which places model construction in authentic context, integrating MEA into engineering curriculum seems an ideal choice to help students develop abilities in design and in problem solving. Incorporating MEA into engineering courses effectively, however, presents challenges, particularly in courses that cover a broad range of subject topics in a limited period. Even with many successful stories, MEA implementation requires comprehensive planning, and may need curriculum restructuring. Never the less, the core values of these principles are in line with engineering education objectives, considering the nature of jobs that engineers do [10]. Adapting MEA principles to create suitable learning activities, such as the Engineering Report team project offers us opportunities to engage students in authentic learning in engineering classrooms.

TABLE I. DESIGN PRINCIPLES FOR MEA AND INSTRUCTIONS FOR SOLVING ILL-STRUCTURED PROBLEMS

MEA Design Principles [10]	*Instructional Design for Solving Open-ended Problems [7]*
Model Construction: Design of MEA requires the construction of a model by a student team. A model is often a product of either a procedure for conducting a task or a design for a product.	Define Problem and Problem space; Articulate Problem Context.
Reality: Design of MEA is situated in an authentic context. Context constraints and the needs of the client are considered	Introduce Problem Constraints
Self-assessment: Design of MEA provides opportunities for students to assess the utility of the model from a client's perspective as a team and their own experiences in the context.	Select and Develop Cases for Learners
Model Documentation: Design of MEA requires the documentations of the created model, including student team's responses to the task, a procedural description.	Support Knowledge Base Construction
Model Share-ability and Re-usability (local generalizability):	Support Argumentation and Reasoning Construct
Design of MEA requires justification for shareable and re-usable for other sets of data.	Assess Problem Solution

Decades of research on teaching students to solve problems has supported the fundamental role of ill-structured problems in education [7]. Ill-structured problems are often open-ended and possess multiple solutions and solution paths. They are context constrained and may not include all required elements in the problem statement. They may also invoke various understandings and interpretations of the problem. Much research has indicated that solving open-ended problems is a design process that requires students to articulate problem space and context limits before they start solution processes [7]. Students are also required to recognize and evaluate alternative solution paths before they generate, implement, and evaluate solutions. Learning processes for solving ill-structured problems should help students step out of the boundary of traditional problem solving with a set of procedures, and challenge students to think critically and creatively. These learning experiences are expected to generate genuine interest because open-ended problems are situated in everyday practices, and should be much more relevant and meaningful to students.

Table I lists design principles for MEA and instructions for solving open-ended problems. Consistencies between MEA and solving ill-structured problems instruction design principles can be recognized. For example, the MEA Reality principle for engineering emphasizes the contextual constraints and the needs of the client for model design, and is supported by problem solving instructions on "articulating problem space and context constraints". Both models include the required assessment component to promote metacognitive skills. The table also shows complementary of the two approaches. For example, the Model Construction and Self-assessment principles for MEA stress the teamwork whereas problem solving instructions underscore reasoning construct and resource provision. To integrate pedagogies for MEA and problem-solving into the development of the project, we created an instructional implementation plan for the project, which will be discussed in the following.

B. Research Team, Approach, and Setting

A close partnership between course instructors and the education researcher has been built and supported by design-based-methods for the past four years [1-5, 11]. In spring 2016, the team expands to include a graduate TA and an undergraduate TA. The research team meets regularly every week to make detailed plans for implementation of the project. These meetings allow us not only to monitor the implementation and progresses of the project, but also to make timely changes that improve student learning experiences.

The study is conducted in the Electric Drives course in the Electrical and Computer Engineering Department at the University of Minnesota. The course is offered every spring with an average enrollment of 100 students. For the Engineering Report project, the class is divided into 13 groups. Students voluntarily form groups, and the group size varies. Some small groups have 4 students, and other large groups have up to 8 students. Students who enrolled in the class participate in this study. The study focuses on four research questions: (i) Does the engineering case developed for Engineering Report engage students in a process through which they place their learning in a real world context? (ii) Is the engineering case engaging to students, allowing them to process and produce artifacts in ways that are meaningful to them? (iii) What instructional interventions are needed in the process? (iv) What are the criteria for assessing learning outcomes?

C. Engineering Report Project Implemention Plan

TABLE II. IMPLEMENTATION PROCESSES FOR ENGINEERING REPORT TEAM PROJECT

Time	*Instructions*	*Instructors*
Part (I): 6th week	(1) Project announcement: A team report of engineering opinions and recommendations of functionality and operation principles of a hydroelectric system	The course instructor htpps://www.youtube.com/watch?v=9-4LIv32RY[12]
	(2) System Engineering Report sample PowerPoint presentation	The graduate TA **http://dodcio.defense.gov/Library/DoDArchitectureFramework/dodaf20_viewpoints.aspx [13]**
8th week	The written report is due and is submitted online	
10th week	(1) Online announcement (via Moodle): Engineering Report Oral Presentation---5-min group talk and 1 min for questions	The graduate TA
	(2) Oral Presentation Guide Line: (via Moodle): a) *What is the purpose of the report? b) List all alternative proposals and describe different opinions during the process; c) How did team reconcile (provide reasoning)? d) Summarize main ideas including functional, operational, strengths, and weaknesses; e) Possible improvement and potential application.*	The graduate TA (decisions are made in the meeting)
	(3) In-classroom oral presentation (75 min); Students are asked to use provided rubrics and sheet to review the presentations from other groups;	The graduate TA and the under-graduate TA
Part (II): 10th week	Online announcement (via Moodle): Each group (acting as a client/owner) is instructed to deliver the analytical report to the assigned team for design task.	The graduate TA (decisions are made in the meeting)
11th week	Online announcement (via Moodle): The second part of the report will be due by the end of the following week.	The graduate TA
12th week	The written report for part (II) is due, and is submitted online; extended two days for one group who did not get the analytical report from the client/owner on time.	The course instructor and TAs
12th week	Online announcement (via Moodle) about two design part deliverables: (1) The design team emails the **report** accompanied with **a short PPT** (less than 10 slides) back to the "client/owner" team. The "client/owner" team will grade the PPT slides using provided rubrics by the instructors; (2) The "client/owner" team provides the design team a "**Letter of Response**" (LOR). The LOR addresses any one of the following: *a. The Design Report is accepted. Provide reason.* *b. The Design Report is acceptable, contingent on following minor alterations. (Mention the required alterations)* *c. The Design Report is not acceptable in the current form. It needs to address the following major alterations.* The deadline: the beginning of the 14th week.	The graduate TA (decisions are made in the meeting)

To meet the project goals and engage students in a few key areas of skill development, the project is presented to students with two parts. Table II displays the implementation plan. The first part of the report focuses on the development of skills in problem defining and analyzing, stressed by instructional pedagogies for open-ended problem solving. It requires students to make effort to understand what the project is about and to establish meanings and goals of the project as a team. It also encourages each student to contribute to and to be comfortable with diverse opinions and solutions paths. Students need to attend to not only the final report but also processes leading to conclusions. The second part of the report focuses on the development of design skills. The process is again stressed. The project is expected to offer students both learning content and context through which they take the ownership of learning and develop engineer skills that are practical and essential. The project is also expected to engage students in review processes that are intended to promote self-assessment emphasized in MEA and PS instructions. Students need to review the project and assess the solution from perspectives of a client as well as their own experiences as an engineer.

D. Research Method, Data Coolection, and Data Analyses

Our research methodology comes out of the theories of learning sciences and instructional design, which emphasize cognitive abilities of applying, analyzing, creating, and evaluating [14]. Through this method, we conceptualize instructional support to solving open-ended problems and develop activities for the Engineering Report project. We create evaluation methods to track project development and student learning progresses, and assess the learning outcomes.

Data collection includes:

(1) Video recording of team oral representations
(2) PPT slides for both Part I and Part II of the Engineering Report
(3) Students' evaluation sheet
(4) Students' written report for both Part I and Part II
(5) Student team's Letter of Responses (LOR)

III. Results of Engineering Report Part (I)

A. Team Presentation and Peer Evalutaion

Each team was required to give a 5-min oral presentation and was provided peers' review scores after their oral presentation. These scores were tabulated by the TA, and the average score of each item for every team as well as for the class was calculated. The scores for the class are shown in Fig. 1. The figure also includes the rating from the TA who used the same rubrics. The rubrics (R1- R5) are shown in Table III. More than 80 students submitted review sheets. A scale of 1-3 is applied: 1-disagree, 2-neutral, 3-agree. Sound reasoning, R3, and specifying resources and tools, R5, have relatively lower average scores of 2.69 and 2.56 in student rating. The rating from the TA shows a lower rating for both R3 (2.0) and R5 (1.92) as well. The consistent trend between students' and the TA's rating proves to be significant by a paired-t-Test with p-values less than 0.01.

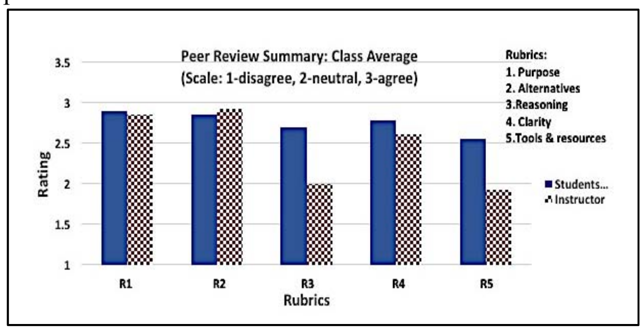

Fig. 1. Peer review and TA rating for in-class oral team presentation.

TABLE III. Rubrics for Team Presentation Evaluation

	Oral Presentation Review Rubrics Descriptions
R1	The purpose is clearly defined.
R2	Alternative ideas and goals are considered.
R3	Reasoning for finalizing the proposal is sound.
R4	The proposal(s) is concrete and is presented with clarity.
R5	Resources and tools are specified.

Here, two observations by TAs and the researcher who attended the session are described. (1) High attendance and "team spirit": about 90% of the class came to the presentation session. Some groups had all members standing in the podium even though not everyone talked. Others delegated the task so that each member presented one topic. Out of 13 groups, only one group had a single speaker. (2) Engaging in reviewing process: students who attended to other groups' presentations completed and submitted the provided feedback sheet. We also noticed that no questions were raised during the presentation, however.

B. Written Report (Part I)

Students' written report was assessed using a developed scheme that includes two measures: (i) Approach, and (ii) Organization. The "approach" part assesses methods applied to define, plan, and complete the task. There are four categories under "approach": (i) defining problem statement (i.e. purposes and scopes of the project); (ii) offering alternatives; (iii) providing reasoning and evidence; (iv) highlighting the significance of the proposal (proposals). Table IV displays rubrics for "approach". The "organization" part measures the effectiveness of message and idea delivery. Four categories are under "organization": (i) providing purpose or overview; (ii) presenting tangible proposals with clarity; (iii) applying multiple representation modes; (iv) communicating in effective ways. Table V shows rubrics for "organization". Both measures employ a scale of 1-3: 1 means "disagree", 2 "neutral", and 3 "agree".

Fig. 2 shows the written work evaluation scores using "approach" rubrics displayed in Table IV. Although the average for the four areas under "approach" is not significantly different, disparities among groups for specific items are noticeable. Two out of 13 groups earned a perfect score for all four measures (total of 12), and three groups had a lower total score around 7, less than 60% of the perfect score. While the class average for the category of applying multiple representational modes is 2.53, a couple of groups had a significantly lower score of 1. The rating for the final proposal also measures the significance: if the recommendation is limited to fixing obvious structure flaws and stopped short in proposing future applications or presenting the potential of the system, the rating score is marginal satisfaction of 2 or lower. The class average of 2.15 in this area is the lowest of the four ratings, which, we believe, is majorly affected by the defined problem statement. The data show that groups who scored lower than the average of 2.38 in the area of defining the problem statement had their overall score lower than the class average of 9.46. Students' ability in defining problem spaces is the key for the overall quality of the report.

TABLE IV. Rubrics for "Approach" Measurement

Label	Descriptions
APPR-1	*Defining problem statement*
APPR-2	*Offering alternatives*
APPR-3	*Providing reasoning and evidence*
APPR-4	*Highlighting the significance of the proposal*

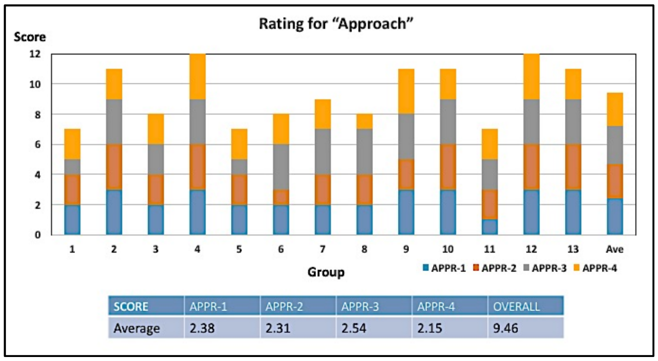

Fig. 2 Rating of "approach" measurement for written report. Rating rubrics are shown in Table IV.

TABLE V. RUBRICS FOR "ORGANIZATION" MEASUREMENT

Label	Descriptions
OR-1	*Providing purpose or overview*
OR-2	*Presenting tangible proposal(s) with clarity*
OR-3	*Applying multiple representation modes*
OR-4	*Communicating in effective ways*

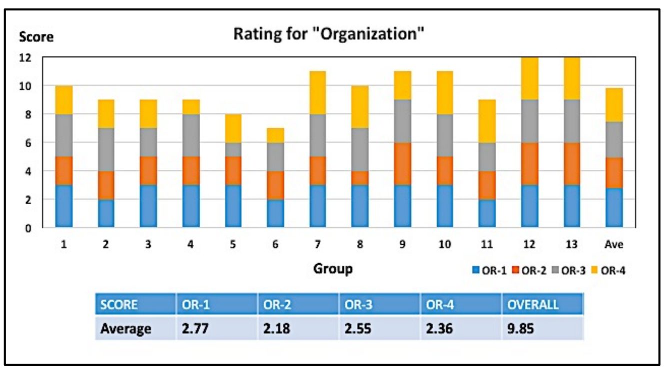

Fig. 3. Rating of "organization" measurement for written report. Rubrics are shown in Table V.

Fig. 3 displays the rating for "organization". Electrical Engineering students are required to take 3-4 credits of "writing intensive" engineering courses. Although many juniors and seniors have become familiar with tech writing, about 40% of the class have not had trainings in tech writing. This explains the observation that some groups, for example Team 4, score high in "approach", but fail to communicate their ideas in coherent ways. The Engineering Report project does not focus on writing skills. Nevertheless, scores in this measure give students information on the effectiveness of their communications with their "clients" and general readers as an engineer.

IV. FINDINGS AND DISCUSSION

In this section, we discuss a few findings that provide insights into the four research questions described in Section II. The data indicate that ways in which students engage the Engineering Report team project have significantly influenced their abilities in placing their learning in context and in producing meaningful artifacts. The data also indicate areas that demand instructional interventions to facilitate learning. The engineering case developed for Engineering Report generally involved students in processes through which they gained experiences and developed skills for a real engineering world. However, uneven learning outcomes are observed as shown in Figs 1-3. There are disparities in teaching and learning objectives as well. Some students are not sure how course content learning is applied to the project while struggling in defining and interpreting the problem.

A. How do students appraoch the Engineering Report team project?

Before we discuss students' performance, we first describe the intended cognitive activities for the project. There are three main cognitive activities: (i) Defining problem spaces (statement and model) that include elements of problems and the project through inquiries; (ii) Analyzing strengths and weaknesses of the situation/system with reasoning and evidence; (iii) Evaluating and synthesizing multiple resources based on collected evidence.

i. Defining problem statement through inquiries

In Sections I and II, we state that the Engineering Report project presents students with tasks in an analogy to open-ended problems. Open-ended problems do not provide students with a problem statement and are not necessarily bound to course content in certain textbook chapters. These problems do not limit students to follow a predetermined solution path. Instead, they challenge students to think big and encourage students to take untraditional methods guided by critical thinking. However, open-ended problems do present context constraints, and require students to articulate problem space and interact with constraints and a broad range of content knowledge. Given the nature of open-ended problems, defining problem space (problem statement and problem model) requires students to understand what the task is about and what the constraints are. To include all possible elements and causes of the problem, students are expected to make inquiries, explore ideas, and engage in quality questioning as a team. Processes of defining problem spaces should help students make the project purposeful and meaningful. The defined problem statement then guides processes of planning and plan execution. It is the foremost strategy in solving open-ended problems, which is applicable to the Engineering Report project. We expect students to take time in formulating purpose and scope of the project collaboratively, which is the central part of the problem space and problem model.

ii. Analyzing strengths and weaknesses of the system with reasoning and evidence

Searching solutions to open-ended problems is a design process that begins with thoughtful and thorough analyses. The ability to analyze strengths and weaknesses of a system is built upon conceptual understanding of functionality and operational principles. Students are expected to first identify relevant and applicable knowledge and then apply their prior knowledge and experiences to describe how the system works within the context constraints. Systematic approaches are not always appropriate in analytical processes for open-ended problems. In order to agree upon what defines “strengths” and what defines “weaknesses”, students need to learn how to recognize different perspectives and take context constraints into account to negotiate with team members. They need to provide extensive and compelling reasoning while accepting or rejecting various opinions. They also collect evidence to support their argument.

iii. Evaluating and synthesizing multiple resources

Solutions to open-ended problems are not unique, and solution processes require inquiries into multiple resources. Evaluations are critical in creating a common ground in agreeing on and selecting the “best” one. Synthesizing multiple resources to form one’s own solution requires students to compare and contrast available options. Criteria need to be established to evaluate consistencies and/or contradictories between different resources. Each team member usually chooses the one that is preferred based on individual’s mental model of the problem. It is important that the group shares and refines the model based on the defined problem statement.

The four items under “approach” are intended to understand students’ beliefs and behaviors while planning and conducting the assigned task. As shown in Fig. 2, groups who did not score high in “APPR-1”, defining problem statement and scope, were not able to generate a quality engineering report. Without articulating problem spaces and identifying problem constraints, students had difficulties in recognizing goals and interpreting problems, making the project less interesting and relevant to their life experiences and learning. Tables VI – VIII display samples of students’ written report. These examples are used to illustrate students’ approaches to the project while engaging in cognitive activities.

Table VI shows samples of students’ work concerning “purpose” and “scope”, the problem statement for the project. The first group, shown in the left column did not come up with well defined problem spaces including “purpose” and “scope”. It includes only given information and omits some important elements of the problem, which are not provided. Because students in Group 1 attend to physical size and other facts, the defined purpose is limited by known specifics. In contrast, Group 2 clearly states what the task and the scope of the project is and has considered perspectives from others, such as the client or the owner of the system leading to quality proposals that will be discussed in the following.

Providing reasoning is essential for analyses. In order to offer reasoning in a comprehensive way, critical thinking is the key to enable judgments for analysis. Often times students may need to begin with conjectures, and work through details to find inconsistencies and discrepancies. These practices are unquestionably influenced by the defined “purposes” and “scopes”. Table VII compares ways in which students offer reasoning. In some way the data help explain why “reasoning”, R3 shown in Fig. 1 is rated relatively lower than the other scores. The work shown in the left column provides reasoning concerning weaknesses of the system in terms of the system safety. When students attended to the functionality of a hydroelectric system, they are expected to hear reasoning for major concerns from electrical engineering perspectives. The work from Group 2 (right column) is the kind that is expected. In comparison, the limited work from Group 1 does not meet the expectation.

TABLE VI. EXAMPLES OF STUDENT APPROACH TO THE PROJECT

“Purpose and Scope” *Defining Problem Space*	
Group I	*Group II*
“As engineering students, we will analyze how the device uses mechanical energy to generate electrical energy. We will take into consideration the dimensions of the wheel, the flow rate of the water, torque of the wheel, the diameter of the gears at the end of the shaft and other relevant factors.”	“The purpose of this report is to analyze the design and functionality of the overshot water wheel presented in lecture as well as propose recommendations for improvements, future use, and/or expansion of the facility. --- The scope of the overshot water wheel improvement project has two main categories, what is in the scope & what is beyond the scope of our engineering analysis.---”

TABLE VII. EXAMPLES OF STUDENT APPROACH TO THE PROJECT

Analyzing Strengths and Weaknesses with Reasoning and Evidence	
Group I	*Group II*
“In terms of the overall design, there are some concerns about how the system is implemented, mainly regarding safety. First, we notice that there are no guards or covers on the gears and belts. Although the system is ---, there should be something protecting the gears from any possible obstruction. The gear system’s protection should eliminate the contact between metal and water to avoid the oxidizing and water pollution. The gear lubricant should be provided ---, also increase the efficiency of this electric generation process. Second, we notice that the generator is connected with loose and open wires. These should be isolated or covered for safety, especially since they are in close proximity to falling and splashing water.”	“Electrically, we noticed that there was a flywheel attached to the 3phase generator. We would recommend keeping this design due to the fact that flywheel helps to spin the generator at a constant speed when there are fluctuations in the water supply and ultimately fluctuations in the rotational speed of the water wheel. Since the frequency of the output voltages is based on the time period it takes a specified magnetic polarization on the rotor to consecutively pass a single coil on the stator, the constant angular speed provided by the flywheel with help with the frequency stability of the three phase voltages that are created by the generator. ---”

In similar ways, evaluating and synthesizing multiple resources requires reasoning and evidence just as what are discussed in the analyzing activity. The cognitive activity of evaluating and synthesizing multiple resources is important because students are encouraged to appreciate and consider alternative solutions. Students are challenged to evaluate and synthesize multiple resources, and make some of these new and unfamiliar ideas to become their own. The quality of the proposal(s) is directly influenced by their ability in evaluation and synthesis. Table VIII compares the work, concerning "evaluation" and "synthesis", from the same two groups shown in Table VI. The quality of the work is affected by that of the project statement as well as the ability of evaluation and synthesis.

TABLE VIII. EXAMPLES OF STUDENT APPROACH TO THE PROJECT

Evaluating and Synthesizing Multiple Resources	
Group I	*Group II*
"This is a typical power generating waterwheel in which the flow of water comes from above and slightly beyond the center of the wheel. The water fills buckets to propel the wheel, which in return rotates the generator to produce electricity. According to our estimates and calculations, the efficiency is over 50% for now. The physical dimensions of the wheel and the height of the water flow relative to the wheel determine the mechanical power the generator can produce…"	"Physical Design Options Design Option 1: Redesigned Waterwheel & Electrical System Upgrade" "Overview: Reuse existing wheel, flip direction of buckets by removing wheel and spinning 180 degrees; Build "Pentrough and nozzle," shown above using plywood;…Total Project Cost: $14100. See Appendix A for Budget Return on Investment: 7 Years" "Pros: Increased efficiency due to new Pentrough design; Higher power output - can power an average sized house; Low Cost option; ---" "Cons: Routine maintenance required: clear sticks, lubricate bearings, etc.; Takes up a lot of space on property; Low power output compared with Design Option 2, no room to expand load; Lower return on investment compared with Design Option 2; Higher Minimum Efficiency Required, lower chance of success. "Design Option 2: Inverted Pump Generator & Electrical System Upgrade" "Overview…" (Not shown are figures of both the current system and the proposed one and references).

By comparing students' work, we find that students apply various approaches to conduct the project. We speculate that students who applied traditional approaches using only what they already knew to find solutions engaged less learning in a real-world context. In contrast, students who were able to break traditional boundaries maximized their learning and gained positive and significant learning outcomes. These students were able to not only apply prior knowledge and experiences but also explore and assess new ideas to take ownership of the project and learning.

B. How do instructions influence student performance ?

Instructional interventions play an important role in improving students' learning performance. First, because the general direction was provided, every report included and worked around "engineering opinions about functionality and operational principles" as instructed. Second, many groups used the terminologies introduced by the TA in the PowerPoint presentation. Groups who utilized languages and approaches introduced in "system engineering report" shown in Table II were likely to go beyond what they knew and what were taught. Students in these groups were industrious in understanding not only what the project meant to them, but also to others in reality. As shown in Fig. 2, eight out of 13 groups made such an effort and delivered a high quality report. Third, Instructional interventions for oral presentation and peer review have improved student overall engagement. As discussed in Section III, students were asked to provide feedback to peers using the provided rubrics. It gave students an opportunity to learn from their peers and reflect on their own work as well. This is particularly important for the project because there is not yet a mechanism for assessing individual's contributions to the team project. Strengthening peer interactions is one way to involve the majority in the process.

There are certain areas that demand instructional interventions. Some are discussed in Section II BACKGROUND, indicating that the needed interventions are consistent with MEA design principles and pedagogies of PS instructions for open-ended problem. First, to mend the gap between instructional goals and student learning perspectives. Students' oral and written report indicated that some students were not able to place the learned course content in context in meaningful ways. Only four groups applied course content of circuit, generator, machines, etc. to system analysis and application. Most groups touched upon mostly basic concepts in mechanical engineering content knowledge. Learning activities that offer students opportunities in constructing the content knowledge base that is practical and meaningful should be included in engineering courses. Second, to help students articulate problem spaces, attend to key elements and causes of the problem, and define the problem statement that leads to critically reviewed and creative solutions and proposal. In order to develop and strengthen problem solving skills for a real-world engineering problem, instructions and practices to motivate and to inspire students in breaking the boundaries imposed by traditional thinking and approach are needed. Instead of taking time to articulate problem spaces, some students reported that they in fact awaited explicit instructions [15]. Instructional interventions that help students to understand that the "essence of the engineering approach" is "using models to make proper decisions" should be reinforced [16]. Students need to understand that engineering is not only about designing and making things, but also about developing "an explanatory framework that identifies and validates a particular solution to a problem as the best", which is at the center of MEA principles [10, 16]. Third, to strengthen peer interactions that allow students to compare and connect their work with their peers in responsible ways. Instructions that encourage students to provide feedback for their peers and to ask quality questions during the process are needed. They are stressed specifically by MEA principles of self-assessment and share-ability. PS pedagogies for ill-structured problems recommend introductions of context and reality constraints. In general, instructions for Engineering Report should not only be inline with course instructions, but also be complementary, which highlight skills for real-world problem solving.

V. Summary and Future Work

We report data from a pilot study, which show that Engineering Report can be employed as a tool and has the potential in facilitating problem solving in real-world situations. Students are motivated and engaged in the activity in general. Students in some groups are able to use this learning opportunity to enhance cognitive abilities of applying, analyzing, creating, and evaluating, included in the 2-D taxonomy for engineering instructional objectives [14]. It is not surprising that some students are not able to apply unfamiliar methods and fail to think beyond what they know and what they are taught. Interacting with real world situations is difficult and challenging. In this respect, regular in-class problem solving activities are limited in terms of providing authentic learning environment for articulating problem spaces and context constraints. The observed uneven learning outcomes and performance indicate that instructions for scaffolding solving open-ended problems are necessary and need to be strengthened. These instructions will make the project relevant to course content learning, which further motivate students to place their classroom learning in context and with meaning.

Some future work has been planned: (1) Using survey to ask students to report in what ways they contribute to the project as an individual and as a group. (2) Refining rubrics to review student team report. (3) Developing models for the three cognitive activities. (4) Improving methods of providing timely feedback.

Finally, we want to comment on TAs' contribution to the project and to reform teaching and learning in general. It is invaluable that the course TAs participated in every stage of this study, including instruction design, implementation, and research. The undergraduate TA who took the course in the previous year provided us with the first-hand information regarding "being relevant and being exciting". The graduate TA took the responsibility in making announcement and in providing timely instruction. The design-based research offers us an opportunity to improve the project based on research results. Yet, with limited budget and resources, it can only be realized when TAs are involved.

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