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Board 168: Preliminary Design of an Engineering Case Study for Elementary Students (Work in Progress)

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Abstract
The dominant stories about engineering in the media illustrate a field with a chronic shortage of engineers and where "doing engineering" is about math, science, and building. Recent literature reviews examining engineering practice and engineering careers provide a broader picture of what engineers do within their positions and how we conceptualize an engineering career. To complement existing work developing approaches for broadening participation in engineering by bringing engineering into K -12 spaces, the purpose of the study described in this work-in-progress is to create representations of engineering work and careers for K-12 students through the use of engineering case studies. A qualitative design was used to answer the following research question: What components within an engineering case study at the elementary level are needed to illustrate engineering work, careers, and the real-world application of engineering concepts? Case studies that can provide more accurate representations of engineering practice and careers and promote interest in engineering will continue to support existing efforts to integrate engineering into K -12 education.

Motivation
The dominant stories about engineering in the media illustrate a field with a chronic shortage of engineers [1]. In these dominant stories, K-12 students are exposed to powerful messages about what engineering is (e.g., a field for students who are proficient in math and science, where you build things, where there are many well-paying jobs if you just complete the degree) [2]. These and similar narratives can have significant consequences on students' transition into, through, and out of engineering. For example, the focus on engineering as building can turn students away from engineering, who might flourish in highly computational spaces. When considering elementary school-age students as another example, even at their young age, their educational experiences, where many of these narratives can surface, have the potential to affect their career aspirations [3]. Thus, for those K-12 students who are interested in engineering, there is a need for exposure to engineering outside of mathematics and science lessons [4], [5] and exposure to a broad understanding of career practices to maintain their interest and connect a variety of their abilities to the field [5].

Recent literature reviews examining engineering practice and engineering careers provide a broader picture of what engineers do within their positions and how we conceptualize an engineering career. In 2013, engineering education scholars called for more in-depth and specific representations of engineering work and engineering career pathways [6]. Up to that point, scholars recognized that research on professional engineering was too sparse, doing a disservice to engineering educators seeking to understand how to better prepare their students for engineering careers.

Even with studies furthering our understanding of engineering work and careers [7], there is a need for additional representations of engineering in the K-12 space. The purpose of this work-in-progress is to showcase a process for developing an engineering case study for elementary school students to improve their understanding of engineering design concepts and engineering work. By focusing on elementary school students, this work seeks to fulfill the need for engineering practice and career discussions before middle school, where students begin to decide whether STEM-related careers are right for them [8].

Overview of Engineering Case Studies

Richards and colleagues [9] defined engineering cases as "an account of a problem, technical or business issue, or design challenge" (p. 375). These problems or challenges are often based on actual experiences and/or are designed to simulate authentic issues that engineers may face [9]. Case studies have been used for decades within engineering to assist professional engineers with their current job duties and students training to be engineers [10], [11], with topics spanning ethics, failure, and design in the engineering disciplines [12], [13], [14]. The pedagogical foundation for case studies is based on problem-based learning models, often associated with business, where the case method is prevalent, and the medical profession [15], [16], [17]. In a problem-based learning context, the learner solves authentic, discipline-specific problems, which are often ill-structured or complex, with many possible solutions and a requirement to collaborate with others [17], [18]. While case studies are not always implemented this way in the classroom, they support active learning and connect content to real-world phenomena.

Given the versatility of case studies and the evidence of their use across levels of the education system and disciplines, multiple researchers and scholars have recommended and/or have used case studies to teach novices such as K-12 students or educators. Kelley [19], for example, states, "One of the greatest benefits of using engineering cases to teach engineering design to a novice is that there are no prerequisites in the study of an engineering case study; generally, anyone can learn about engineering through engineering cases" (p.7). Studies of case study use with secondary students reported improvements in understanding of problem-solving, aspects of the engineering profession, business and engineering, research skills, and decision-making ability [20], [21]. Looking at the needs of educators, Avsec & Kocijancic [22] and Gunbatar and colleagues [23] found the structure of the case study could easily be incorporated within the existing curriculum and assist educators in designing better engineering problems for secondary students. Overall, these researchers present evidence that supports Kelley's [19] claim of the benefits of using engineering cases with novices.

Engineering Case Studies and Design Challenges

Although engineering cases are used at the secondary level, there is little research on cases that are used at the elementary level. Research pertaining to engineering at the elementary level often recommends design challenges as a way to develop students' problem-solving skills [24], [25], [26], [27]. To explore the opportunity for leveraging case studies in elementary education, we began by examining the elements of both case studies and design challenges. Richards and colleagues [9] define five elements of a case study: Relevance, Motivation, Active Involvement, Consolidation/Integration, and Transfer (see Table 1). There are multiple similarities when compared with the elements of a design challenge (see Table 2). For instance, the active involvement element requires effective communication with peers to come up with viable solutions. Given these similarities and the ability of a case study to connect to the practices of engineers, there is an opportunity to examine the potential for this pedagogical method within engineering education in elementary classrooms.

Table 1 Case Study Elements

Elements	Description
Relevance	Cases illustrate the actual situations as they are encountered
Motivation	The real-life situation of the case "allows the students to immerse themselves in the situation" p.375
Active involvement	Students must engage in conversations and discussions about the situation with their peers to come up with resolutions
Consolidation/Integration	Students need to be able to call upon knowledge/concepts they know and integrate new knowledge from the situation
Transfer	The knowledge and skills the students develop using cases can be transferred to other situations, problems, and professional career

Table 2 Case Study Elements in a Design Challenge

Design Challenge	Case Study Elements
• A real-world context motivates students to engineering • Portrays engineering as part of everyday life • Portrays how engineers help the environment, society, and people	Relevance
	Motivation
• Use of physical manipulation enables students to make sense of relationships that are abstract • Discussions of ideas with peers assist with revising thinking • Communicating with peers assists in either confirming evidence or critiquing ideas using evidence	Active involvement
• Enables students to use their developing scientific, mathematical, and technical skills with reading and writing like professional engineers	Consolidation/Integration
	Transfer

Case Study Development and Research Methods

The purpose of the work described in this WIP is to create representations of engineering work and careers for elementary-age students through the use of engineering case studies. Through the development work described here and the ultimate implementation of our engineering case study, we seek to address the following research question: *What components within an engineering case study at the elementary level are needed to illustrate engineering work, careers, and the real-world application of engineering concepts?* In this WIP, we outline our development process and the empirically-informed components that were found based on a synthesis of existing literature on pre-college engineering skills and engineering practice. The next phase of the research will include a qualitative research design to evaluate the case study based on feedback from engineering professionals and elementary school students to more comprehensively address our research question.

Case Study Development Process Overview

Our process for developing the case study was adapted from Richards and colleagues [9] and Stacey and colleagues [28]. The following four steps will be used, with the first three as the focus of this WIP: (1) Exploration of learners' needs and competencies, (2) Definition of goals and topical areas, (3) Information gathering and case development and (4) Evaluation and refinement. Part of the evaluation phase will include field-testing by 5th-grade students.

Exploration of learners' needs and competencies

In addition to the case study elements summarized by Richards and colleagues [9], case study developers need to consider the knowledge and skills they want learners to gain from the experience. Giulioni and Voloshin [29] outline the following questions about considering who the learners are: (1) What knowledge do you want learners to walk away with?, (2) What problems do you want the learner to be able to solve on the job? and (3) What techniques do you want the learner to adopt? To adapt a pedagogical tool often used with older-age groups, we grounded our exploration of the learners and the knowledge we wanted them to walk away with in research on how elementary students learn and comprehend engineering [27], [30]. In a systematic literature review of the past two decades of elementary-level empirical studies, researchers isolated five broad categories of students' engineering skills and practices [31]. The five categories are as follows: (1) content knowledge, (2) engineering design practices, (3) engineering thinking, (4) professional skills, and (5) STEM career understanding. Briefly, *content knowledge* includes STEM content broadly, *engineering design practices* encompass the design process and design principles, *engineering thinking* covers systematic decision-making and discourse, *professional skills* entail practicing professional engineering skills, and *STEM career understanding* encompasses the broad range of what engineers do as a profession. Of these five broad categories, Crismond and Adams [2] note novice engineers at all academic levels have difficulty with aspects of engineering thinking, specifically problem scoping, which is a key component at the beginning of the design process that influences the quality of solutions. Given the importance of proper problem scoping, we decided to focus the case study on enhancing students' understanding of problem scoping in the context of a design process.

Definition of goals and topical areas

Based on our exploration of the competencies and needs of elementary students within engineering, the resulting case study previewed in this WIP is based on human augmentation where different team member's expertise and knowledge are considered. To provide the context for the case study, we sought to connect to existing work on engineering practice and engineering careers. Two particular areas within those spaces were selected: (1) persuasive communication and (2) cross-disciplinary communication [32], [33]. Existing research has highlighted the importance of not only engineering students' developing these communication competencies but also the value of students simply being exposed to empirically-informed examples of communication practices (i.e., these activities are part of an engineer's work) [7], [32], [33].

Information gathering and preliminary case development

Our process for gathering information and developing the preliminary version of the case was an iterative process to both develop an authentic problem for the case itself and ensure we were adequately considering the elements of a case study. To begin, we explored each required element of a case study (see Table 1) to determine to what extent the element was appropriate given our learner population.

When considering *relevance,* we recognized that there are many professional engineering situations that are illustrated in everyday life that elementary students can comprehend. Yet, this element would be an important consideration in examining possible contexts for the case study.

With the increase in Augmented and Virtual Reality within consumer products, and narratives about other forms of human augmentation (e.g., exoskeletons), we viewed this as a context that elementary students could discuss.The components of consolidation/integration and active involvement require one to draw on students' critical thinking skills, for example, making evidence-based decisions based on presented information and additional research. Making such informed decisions is an ability that elementary students possess. The components of motivation and transfer had to be reframed for this context. To ensure elementary students could access the narrative, the readability level of sentences in the text was modified to a 5^{th}-grade level. The change allows elementary students to immerse themselves in the situation better, a key of the motivation component. The intended purpose of the transfer component is to support the learner in using the skills in other engineering situations. For younger learners to transfer engineering practices and skills to another situation requires engaging in multiple experiences [34]. The designed case is standalone; therefore, the transfer component was excluded.

The preliminary case study was developed with four dimensions in mind: problem-scoping, persuasive communication, cross-disciplinary communication, and material science. Each of these dimensions are presented through discourse among team members working on a human augmentation project with the aim of allowing students to consider how each of these dimensions plays a role in a design project and a design team. To create that discourse for the problem-scoping dimension, as an example, the case studies found in open-access engineering case studies libraries were appropriate for elementary students but not for the topic of problem scoping. As a result, the discourse was based on both accounts of professional engineers engaged in problem scoping found in design research and a collaboration with a professional engineer to refine aspects of how problem scoping happens in the context of material science. A detailed description of the four dimensions, how the dimensions were developed from the literature and contributions from practicing engineers, and how they will be presented across discourse from three different design teams is included in Appendix A. Lastly, the preliminary case study is presented in Appendix A with the dialogue of one design team included.

Conclusions and Future Work

Case studies that can provide more accurate representations of engineering practice and careers and promote interest in engineering will continue to support existing efforts to integrate engineering into K -12 education. To support the efforts of integrating engineering at the elementary level, future work will focus on refining the case study to include three different design teams (see Appendix A) and conducting a field test of the case study in 5^{th}-grade classrooms.

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Appendix A

Characteristics of Team Interaction Across Four Dimensions

Dimension	Novice (Team A)	"Informed" (Team B)	Blend (Team C) (informed/novice)	References
Problem-Scoping	Generate ideas right away, focused on the "best" ideas	Focus on trying to make sense of the task or problem	Try to understand the problem and discuss context but some team members fixate on an idea	[2]
Persuasive Communication	Team members "tell" the others what should be done	Tries to reach a shared understanding	Documents the thinking of all members, but overall, decisions are made using little evidence	[33]
Cross-Disciplinary Communication	While there are points where all talk, certain team members lead the discussion	Not perfect. Some team members want to learn from others, while others want to push divide and conquer	Engineers are the only ones engaged	[32]
Material Science Application (Human Augmentation)	Consider the product and not the people who use it	The benefits and tradeoffs for the people and product are considered at the same time	Use optimization tools to justify their rationale, decisions, and tradeoffs	Professional Material Science Engineer

Case Introduction

Given that the elementary engineering case is a multipage document, a condensed version of the case is presented due to page limitations. The case includes a description of the engineering context with the task and one of the three professional engineering teams' transcripts. Three teacher prompts are included for the condensed case to facilitate the student discussion around problem-scoping, persuasive communication, and cross-disciplinary communication.

1. What key factors did the team discuss when considering ways to change an existing exoskeleton to make it even more helpful to people of all ages?
    a. What additional factors should they have discussed? Why or why not?
2. Why are there differing opinions between team members about whether the technology or healthcare sectors should be considered in exoskeleton design?
    a. How does this discussion impact the overall approach to designing exoskeletons?
3. In what ways did the team members try to convince one another of their viewpoint?
    a. In what ways did the team members try to come to a shared understanding of the problem?

Case Summary

Human augmentation is when technology is used to make humans better at different things. It can help with physical abilities, senses, thinking abilities, and social skills. The technology is designed so anyone can use it. The goal is to help as many different people as possible.

Inventions in human augmentation make life better for people. They help restore lost abilities, make people more productive, and improve what they can do. Some examples of these inventions are VR/AR headsets, fake limbs, exoskeletons, and things that make the senses stronger, like being able to smell different things. These inventions are made for all kinds of people, no matter their age.

One company that focuses on making products better for people is an Inclusive Design Development firm. They are studying exoskeletons to see how they can make them even better. They found out that the exoskeletons on the market can be used in many different situations in people's lives. They can help with moving (like running, walking, hiking), working in very hot or very cold places, and doing different kinds of movements (like bending, squatting, lifting, turning). The team at the firm is working together to come up with ways to change an existing exoskeleton to make it even more helpful to people no matter their age ability.

The team includes a materials and science engineer, a human factors specialist, a clinical expert, a mechanical engineer, a computer engineer, and a biomedical engineer.

Review each engineering team conversation to answer the following questions:

1. Which team's method seems like it would come up with the best result(s)? Why?
2. What are the pros and cons of each team’s method of solving the main problems and sub-problems? Use the teams' conversations to support your answers.
3. What skills do the engineers on each team have?
4. Which team would you want to be a member of? Why?

Conversation from Team A

Materials and Science Engineer: Alright. Let’s get started. Our goal is to add to our EXO5000 exoskeleton product to make it better so that many more people can use it. We need to figure out the important things to focus on before choosing an exoskeleton. Any other ideas?

Clinical Expert: Based on our knowledge, we should consider the groups of people who would be using this product with the needs of an exoskeleton and make a list together.

Everyone agrees

Materials and Science Engineer: The materials used and who will use the exoskeleton are important. Adults vary in abilities, so weight, strength, flexibility, toughness, and heat are key. The material should fit the needs of the different people we are thinking about. Cost isn't a concern yet because we don't know who will use it.

Clinical Expert: True. And here's what I'm focused on: how comfortable the exoskeleton is, how easy it is to use, and what injuries that could happen if not used correctly.

Human Factors Specialist: I agree. We need to make sure the exoskeleton is easy to use and comfortable for people. We must pay attention to how the person's body will move with the exoskeleton and if it feels natural. We also need to think about what feedback signals the exoskeleton gives the person. We need to make sure the setup is not confusing for someone to use. The pressure points on the body at rest and in motion are another thing.

Mechanical Engineer: I am thinking about the forces and stresses the materials can handle for the exoskeleton and how much energy is needed for it to work. If batteries are part of the exoskeleton, then I will have to think more about heat transfer and materials. The materials and structure will depend on who uses the exoskeleton.

Computer Engineer: I agree with others. We need to consider the materials, the efficiency of the power, the ease of use, and the comfort of the device. We also need to be mindful of how the sensors will work and how different components of software are integrated. If the exoskeleton is going to learn from the user then software upgrades will be important. If the exoskeleton does not need to learn from the user, then the software can be simpler.

Biomedical Engineer: I'm considering the materials, comfort, and naturalness of the exoskeleton's movements. I'm also wanting to think about how the exoskeleton works with different body parts. It is important to understand how the body parts are interconnected to make the big movements we see. If all the parts of the body do not work together in the exoskeleton, then different body parts will not work naturally.

Materials and Science Engineer: Now that everyone has shared their thoughts, we need to create a list of the categories that are important to everyone. These are the categories I heard being talked about: materials, materials combination, components power needs, human body structure, the internal working of the body, human development range (for now, let’s assume adults only), understanding of design by users, software needs, and software integration. Are any categories missing?

Mechanical Engineer: We should use matrices to help us order our needs and make choices as a group. This will help us compare our ideas with existing exoskeletons. Since matrices may not be familiar to everyone, I will explain it. A matrix is a tool to determine how criteria are interrelated, and the criteria are assigned different numbers of importance. I am sure there are ranges of exoskeletons, such as full, partial, and just a body part, so the matrices are a tool we need to consider using.

Materials and Science Engineer: Thank you for explaining matrices.

Biomedical Engineer: Using a matrix is important. Should we use one from an existing project or create our own?

Clinical Expert: Yes, these are great but so much depends on the WHO with this design and the constraints we have from management. When will we be making those decisions?

Biomedical Engineer: Let's add the matrices to our task list for now and come back to them later.

Materials and Science Engineer: Sounds great. I added it to our task list for the project.

Computer Engineer: Now that all that is done, let's consider the exoskeletons. After hearing everyone's needs, I have some ideas about where to start.

Biomedical Engineer: Hold on. I want to go back to the question that was brought up before. How are we at choosing an exoskeleton? Who are our users? What type of exoskeleton are we considering—partial, full, or specific body parts? I think we need to plan the exoskeleton selection a bit more.

Computer Engineer: Companies that focus a lot on exoskeletons are in the technology sector.

Biomedical Engineer: I thought the main companies were in the healthcare sector. Also, that isn't really answering the questions I have.

Computer Engineer: The technology sector for exoskeletons is growing and will soon be the main sector. We should consider future exoskeleton needs to better meet users' needs.

Biomedical Engineer: Can you explain why you are leaning towards this technology sector-focus over healthcare or other applications that come from what we know about the user group?

Computer Engineer: The technology sector designs the exoskeletons that the healthcare sector uses. The healthcare sector buys the exoskeletons but doesn't design them. So, we should first look at the sector that designs exoskeletons to better meet users' needs.

Biomedical Engineer: Oh, okay. I still don't quite understand though. Shouldn't we start with the people we are designing for?

Materials and Science Engineer: This is a good place to stop today. I left a note on our document to remind us to talk about the technology and healthcare sector next time. We got a lot done today.

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