# Work in Progress: Veterinary Medicine as a Context for Student Reasoning in a Mechanical Engineering Capstone Design Course

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Prior research finds that practicing design engineers continue to deepen their understandings of engineering concepts as they work professionally to meet the design needs of their clients [1], [2]. Senior capstone design courses in which student teams are matched with external clients can provide similarly rich environments for conceptual growth [3]. As the students translate the needs of their client into specific and measurable engineering requirements, they encounter opportunities to think in new ways about science and engineering concepts they may previously have only considered in well-defined textbook problems [4]. Working in contexts outside of traditional mechanical engineering applications, students may have to reconcile multiple representations of concepts that they previously perceived more narrowly [5]. Previous research also shows that team projects can facilitate deeper conceptual growth when individual members have to contribute parts to a whole. When teams delegate the design of different sub-systems to different members, to be successful, each individual must understand how their parts contribute to the whole and how they interface with all other parts [6]. Teamwork also presents an opportunity for collaborative knowledge construction as students work together to make sense of unexpected results.

In this qualitative case study, we investigate the range of reasoning used by five different members of a mechanical engineering capstone design team as they partnered with a veterinarian to design a device for horse lung functioning assessment. Technology for veterinary medicine can be a rich and engaging context for undergraduate design projects. Veterinary technologies offer an appropriate level of complexity and provide a new viewpoint on science concepts that are part of the mechanical engineering canon [7], [8]. Moreover, because veterinarians have both very real technological needs and deep STEM knowledge to help mentor students, they can be ideal capstone design clients.

This case study looks specifically at one fourth-year undergraduate engineering team whose capstone design client was a professor of veterinary medicine. The team and veterinarian collaborated to develop and test a working prototype of a portable device to measure horse lung functioning. The system consisted of a mask and tube with sensors. The team had split up into three teams: pressure sensor and shutter mechanism, flow calibration and coding, and mask design. A full diagram of the system can be seen in Figure 1 in the Appendix. The central question for this study is: *How does the crossover of veterinary medicine and mechanical engineering influence the learning and identity development of fourth-year mechanical engineering students?*

## Theoretical Framework

This study draws upon the perspective put forward by Stevens et al. [9] that becoming an engineer entails a three-dimensional process of knowledge development, identification with the discipline, and navigation through benchmarks. Each of these three dimensions becomes more complex over the course of an undergraduate career, as the knowledge to which engineering students are held accountable becomes more aligned with ill-structured workplace problems [10] and identity formation becomes a "double-sided" process requiring both self-efficacy and being recognized by others as belonging to the engineering community [9]. Grounded in this multi-dimensional perspective on the undergraduate engineering trajectory, we examined the influence of the capstone project not only on traditional engineering expertise but also on the ways students were identifying with the discipline and navigating the transition to professional careers.

**Data Collection and Analysis**

Following descriptive case study methodology [11], we collected data to capture evidence of the students' perceived outcomes from the project. Primary data sources include retrospective interviews with the students, all of whom consented to human subjects research participation. The interviews followed a semi-structured protocol (see Appendix) and asked the students to describe the problem and their solution, as well as explain a plot of data produced during a test of their prototype. In the second half of the interview, the students were asked about the influence of the project experience on their conceptual understanding and identity as an engineer.

Drawing from grounded theory methods [12], the research assistant conducted line-by-line open coding of the interview transcripts for evidence of changes in the students' knowledge and perception of themselves. After open coding, we grouped all tagged data excerpts into categories of student outcomes. Finally, we used constant comparative analysis to refine category definitions [13].

**Findings**

We organize our findings by three major categories of student outcomes from the capstone project: *conceptual understanding, practical knowledge,* and *identity as an engineer*. Each of the students discussed some aspects of each of the three major categories. All student names below are pseudonyms.

**Category 1: Conceptual understanding.** Here we highlight the ways in which the project heightened their understanding of mechanical engineering and scientific concepts.

***Fluid flow complexity and assumptions.*** As this project was highly fluid mechanics based, the students had many instances where they noticed that they were cementing the knowledge they learned from classes. In addition, they understood that many of the assumptions they made in class were for simplification of the problems. For example, in her interview Natalie talked about how using Particle Image Velocimetry (PIV) influenced her understanding of these concepts:

> "And I didn't understand what it was when I took that class. But like now I get it, I understand like what's happening.'… Like I'm looking for flow rate and I'm looking for like how much of the air is going this way, and how much is like circling out to the sides."

***Horse physiology and modeling.*** Coming into the project, the students were unfamiliar with designing products for horses. For example, in his interview Noah talked about how they can model and quantify whether a horse is sick or not:

> "Okay, so we're measuring resistance because that is how you can determine how difficult it is for the horse to breathe. So if you think about it, if they have- um if they have a lot of mucus in their system, it's extra stuff in the way when they're trying to breathe. So that would come out as resistance… So we chose to measure uh pressure and flow rate- or [the veterinarian], rather, chose to measure those two because neither requires you to go inside the horse and you can extrapolate resistance from it."

***Manufacturing and materials***. Natalie dove deep into the materials aspect of the project because she was in charge of creating the mask. This led her to learn more about material selection and manufacturing processes. For example, Natalie talked about selecting the material of the mask:

> "The manufacturing process. So like the- some of them I had like I think I had polypropylene, polyethylene and... there was a third one and they were all like either a quarter inch, 3/16 or a 16th of an inch. And um, so essentially like a vacuum forming machine, like has the- the object down here and then your- um your object down here and then you're like, plastic is up here and you just like push it until it forms to the shape of whatever you're molding. Um so the like thicker ones would slip out of the seal. So they weren't like sealing fully, they weren't making this like cone shape. Um and then the fitter- thinner ones were ripping before it got there. Um, so the polypropylene was actually the only one that created the shape that I was looking for."

**Category 2. Practical knowledge.** Below we describe three aspects of the ways students gained practical knowledge about equipment and experimentation.

***Engineering experimentation.*** Coming into the project, the students were unfamiliar with designing their own experiments. For example, in his interview Noah reflected on the challenge of creating an experiment:

> "Um because in classes when you do experiments, they're usually really structured. But for this we had to figure out on our own what we needed to experiment… so kind of the whole process falls on the student and you figure it out."

***Equipment fluency.*** This particular piece of knowledge comes from being able to navigate the equipment being used and transfer the data to analyze it and use it. For example, in his interview Sean talked about how they can transfer data from their sensors over to their laptop:

> "So basically what's happening is the Arduino is like reading values from the- both sensors and can be sent over Bluetooth to your computer so you can read it in real time."

***Equipment limitations.*** Knowing what the equipment being used can and cannot do. For example, in his interview Sean talked about the unidirectionality of the wind sensor:

> "We sort of realized that oh it's actually more useful for the- uh more useful plus we get more accurate data to see the horse actually exhaling and inhaling um in the graph. Because, at first we were just seeing exhale. So it would be like the exhale part would be very good and then there'd be kind of a weak data (set for the inhale)."

**Category 3. Engineering identity.** The students saw changes in how they perceived engineering itself as well as their role as an engineer.

***Appreciation for the discrete subdomains.*** Mechanical engineering is a broad field that students had not always previously seen as always relevant to them. Through this capstone project, the students learned about the connections between the subdomains. For example, Natalie talked about how she began to see the relevance of each of the subdomains and how they intertwine:

> "Um and it kind of felt like some of those, I was like, 'I don't really like it that much and I don't really know when I'm gonna use it.' Um such as fluid mechanics, not my forte. Um but like it- it's that you really do use like all of it… And I know like I've heard people say that, but like I feel like this project (forced me to use), like all of my knowledge of mechanical engineering, like it was (the whole) project. Um, which is cool. Building something from like start to almost finish."

***Communicator.*** This project helped the students see themselves as communicators in different ways. For example, Liam talked about how he most enjoyed working with a client:

> "Um, I really thrived when we were interacting with [the veterinarian], explaining things to her, getting feedback from her… Like it's definitely up my alley, so that was- so that was kind of one big thing that I didn't get a chance to do before in um mechanical engineering was have a client, work with them closely and um get that kind of non-engineering skills down as far as putting technical information into digestible formats."

***Embracer of the "messiness".*** Real world problems often have significantly more complex solutions than what is presented in the classroom. For example, in his interview Sean talked about how he felt like an expert in the field after sorting through the mess:

> "And it just like, it's sort of like once you kind of like, not suffer through it but like have to go through the hard times of figuring out what it is and like all that stuff, you become so like so much of an expert on it because you're just so like- you're researching, and you're trying to- you're exploring all of these different ideas, and you're like investing more time into like figuring out the science behind this."

***Type of engineer.*** For many of the students, even though they were studying engineering, they did not have a clear idea as to what engineers actually did and thus had a hard time figuring out what kind of engineer they would want to be. For example, in his interview Liam talked about how he described himself as an engineer before and after the project.:

> "Um we always joked like 'yeah, (so I'm in) mechanical engineering but I have no idea what a mechanical engineer does' like I think that was kind of a common thing to say up until even like third year. Um and then after this, I was like 'oh if this is what a mechanical engineer does, then I would love to be a mechanical engineer' um so yeah I definitely like solidified the kind of identity of how I see myself um as an engineer."

***Problem solver and figure outer.*** This project was a large one and gave these students the confidence in their problem-solving abilities For example, in his interview Sean talked about this project cementing his abilities:

> "Oh okay, yeah. So yeah, it kind of confirmed and like strengthened like how I (saw) myself as like a problem solver and someone- like an engineer that can really not scared to take on any task and can solve different problems and really can pull from different resources to make sure it works."

## Conclusion

This preliminary analysis shows that the crossover of veterinary medicine and mechanical engineering can be a productive context for capstone projects because they provide an appropriate level of complexity. In this study, we found this project complexity to afford both knowledge development and improved identification with the mechanical engineering profession. These findings suggest that capstone educators consider multidisciplinary projects even when facilitating traditionally single-discipline disciplinary capstone courses.

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**Appendix**

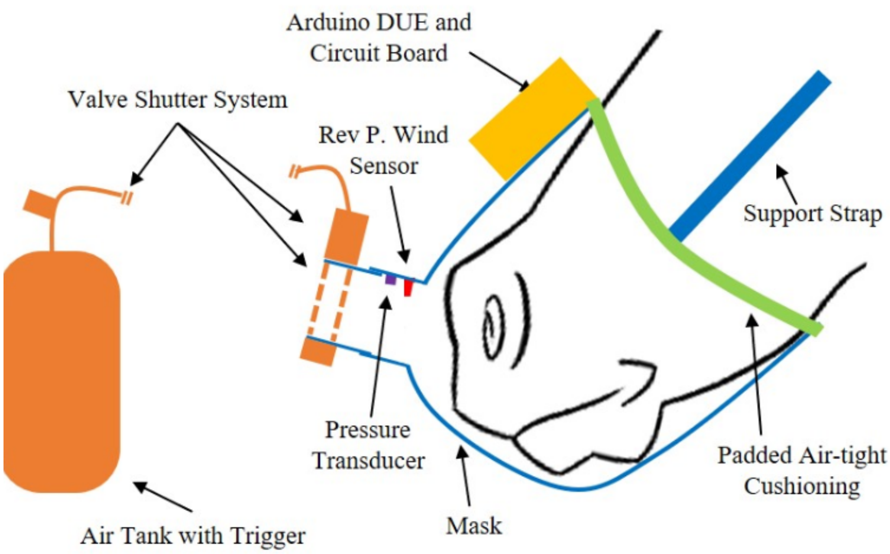


Figure 1: System overview

Figure 2: System on a horse.

**Capstone Design Projects and Student Reasoning Interview Guide**

First part:

Thank you for being willing to talk with me. As you know, I'll be talking with all the team members from Dr. Mazan's project as a way to gather information about how the project influenced your learning and development as engineers. This interview will have two parts. In the first part, I'll ask you to tell me directly about the design problem and your current solution. I think it will be helpful to see the range of ways you all talk about the work itself. I'm sure you'll each have slightly different understandings because you each tackled different parts of the work. For that part of the interview, you can talk with me as if I'm one of the new mechanical engineering seniors considering joining this project. Then, in the second part of the interview, I'll ask you questions that are more geared toward getting you to reflect. The second set of questions will ask how the experience of working on this project affected you.

- Imagine talking to new seniors. They'll have your written report, of course, but in a conversation, how would you tell them about what kind of system Dr. Mazan **needs**?
- How would you tell them about the **current** prototype of the system? While you're talking about it, could you draw a diagram of the system? In other words, I'm asking, what are the parts? What do they do? Why are they there?
- Why are you measuring what you are measuring?
- What problems do you think still need to be tackled? Why?
- Showing them a plot of data that they produced: What does this data represent to you? How would you explain it to the new seniors?
- Describe your design process.
    - (Another option is something like: Tell me, briefly, the story of your team's work on this project – what would you say was the beginning, middle, and end?)

Second part:

- In what ways, if any, has this project *influenced your understanding* of mechanical engineering concepts?
- How has this project *challenged your perceptions of* mechanical engineering concepts?
- This was definitely a group project. How did that aspect of it -- working on this project in a group -- affect your understanding of the concepts and equipment related to the project?
- Did this project affect your thinking about your career trajectory? (If yes, how?)
- Did it affect whether or how you see yourself as an engineer? (If yes, how?)

Additional questions may be asked to probe further, such as "what do you mean by ___?" or "could you say more about ___?", to get the students to further describe the system or their thinking in detail.

**Capstone Design Projects and Student Reasoning Interview Guide (cont.)**