EFFECT OF PERSONALIZED PROBLEMS
IN UNDERGRADUATE THERMAL FLUID TRANSPORT COURSES

A thesis submitted by

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ABSTRACT

Currently, the homework problems used in many thermal fluid transport courses are not engaging for students and can make it difficult for students to see how the course material connects to their own lives or the engineering work they might do after graduating. This is primarily because many of these courses rely heavily on standard textbook problems, which often only have one right answer and lack any connection to the world outside the classroom. In an attempt to develop more inclusive and engaging homework problems for such courses, open-ended design problems based on students' personal lives and interests were incorporated into two undergraduate thermal fluid transport courses in the mechanical engineering department at Tufts University. These problems were assigned as homework, and students completed them in small groups which they selected themselves. Student conversations were recorded as the groups solved the personalized problems and a non-personalized "control" problem (which was open-ended and design-focused but unrelated to students' personal lives and interests). It was found that the use of personalized problems caused students to draw more connections to the real world and to be more engaged with the problem compared with the use of non-personalized problems. The data also suggest that personalized problems did not produce a significant difference in amount of connections to class content, connections to other STEM fields, task production, knowledge construction, student disengagement, and distraction observed during student conversations compared to non-personalized problems. Finally, the data suggest that personalization of problems did not have a significant impact on the balance of participation of the students working together in a group.

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1.0 INTRODUCTION

1.1 Motivation

Currently, many thermal fluid transport courses are not engaging for students and make it difficult for students to see how the course material connects to the world outside the classroom. Thermal fluid transport courses comprise thermodynamics, fluid mechanics, and heat transfer courses, and the vast majority of these undergraduate classes rely heavily on book problems. Most of these book problems are set up for finding the relevant equation and using it to get a single numerical answer. This leaves no room for outside-the-box thinking. Furthermore, the problems are often overly idealized and have little connection to the world outside the classroom or to students' own lives. Figure 1 shows an example of a typical thermal fluid transport textbook problem. Problems such as this may be uninteresting to students because they have no connection to students' lives and interests. The more this type of problem is used, the less students may feel the material they learn in class is relevant to them.

> **15–20** During a high Reynolds number experiment, the total drag force acting on a spherical body of diameter $D = 12$ cm subjected to airflow at 1 atm and 5°C is measured to be 5.2 N. The pressure drag acting on the body is calculated by integrating the pressure distribution (measured by the use of pressure sensors throughout the surface) to be 4.9 N. Determine the friction drag coefficient of the sphere. *Answer:* 0.0115

Figure 1. Example of a textbook problem that could be used in an undergraduate thermal fluid transport course. (Cengel, Cimbala, and Turner 2017)

Standard textbook problems are also not representative of the type of thinking students will need to be successful when doing engineering outside of the classroom. While book problems often supply students with all the values they need to solve the problem and are written in such a way that the steps needed to solve the problem are somewhat clear, real-world problems are often ill-structured, meaning that not all parameters are clearly-defined and there is not one correct way to solve the problem (Jonassen, Strobel, and Lee 2006). Therefore, the person solving the problem must figure out for themselves what numerical values to use and what assumptions can be made.

In an attempt to address these issues, this study incorporates open-ended design problems based on students' personal interests into undergraduate thermal fluid transport courses with the hypothesis that using personalized design problems for students in these courses will increase student engagement with the course material and help students better see how the material is relevant to their own lives.

1.2 Literature Review and Theoretical Framework

Several previous studies have emphasized the importance of using open-ended, ill-structured problems in order to better prepare engineering students for problem solving in the real world (Bornasal et al. 2018; Dixon and Brown 2012). It is expected that such problems are useful because an important goal of engineering courses is to prepare students to use their engineering knowledge in the real world, and engineering problems in the real world are almost always ill-structured. Additionally, the use of ill-structured problems has been shown to increase student engagement and learning (Torp and Sage 2002). In a study specifically done in a university-level fluid mechanics course, researchers found that assigning projects related to the real world increased student engagement and helped students to better see how the material they were learning applied to the real world (Bondehagen 2011). During this study, students enrolled in a fluid mechanics course were assigned projects based on a real-world event, such as a particular oil spill. After completing the problems, students were surveyed on whether the problems had helped them better understand fluid mechanics concepts. The results of the surveys, along with exam results from the course, suggested that student appreciation for the importance of fluid mechanics increased and that student engagement and performance improved as a result of the projects.

Problem-based learning, or PBL, which has been widely adopted across a range of education levels and subjects, relies heavily on the use of ill-structured real-world problems (Savery 2006; Jaeger and Adair 2014; de Graaff and Kolmos 2007). Problem-based learning is learner-centered, meaning that the focus is on the student rather than the teacher, students take responsibility for their own learning, and each student is seen as unique (Savery 2006). Previous work has hypothesized that inclusion of ill-structured, multi-disciplinary real-world problems as in PBL is beneficial because such problems closely replicate the problems students will encounter in the real world (Savery 2006).

Inclusion of ill-structured real-world problems into thermal fluid transport courses could also help these courses better address intended ABET outcomes. ABET, or the Accreditation Board for Engineering and Technology, is the organization that accredits post-secondary education programs in natural science, computing, engineering, and engineering technology ("What Is ABET?" 2020). This organization has established seven outcomes that college programs should address so students in these fields will be well-prepared to solve real-world problems after graduating. When instructors rely on standard textbook problems, many thermal fluid transport courses primarily address only three out of the seven outcomes, as they largely involve solving engineering problems by applying the principles taught in the course, developing and performing experiments, and learning and applying new knowledge. With the addition of personalized design problems, thermal fluid transport courses could potentially address two additional ABET outcomes. By completing design problems based on their real-world interests, students must figure out how to meet certain design requirements while also accounting for "public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors." Additionally, they must consider the broader impact of engineering in "global, economic, environmental, and societal contexts" ("Criteria for Accrediting Engineering Technology Programs" 2020).

To the author's knowledge, no previous research has examined the use of personalized design problems in undergraduate thermal fluid transport courses. However, several studies done using personalized problems in different education settings suggest that using personalized problems in thermal fluid transport courses could have positive outcomes. For example, significant research has been done on the effects of personalization of mathematics problems, particularly for children in grades three through six (Ensign 1997; Bates and Wiest 2004). In a study on fifth and sixth graders learning mathematics, researchers used information about students' family members, pets, and favorite foods to personalize word problems related to division of fractions (Anand and Ross 1987). In this study, the researchers found that using personalized problems had a positive impact on student problem-solving; they caused students to be more interested in the task of solving the problem, improved their attitudes towards the problems, and helped the students feel the application of mathematical concepts was meaningful to them personally (Anand and Ross 1987).

In a separate study performed on 100 third through fifth graders learning mathematics, researchers found that even when as simple of a change as inserting the word "you" into word problems was made, students solved the problems faster and with higher accuracy than when “you” was not used (d’Ailly, Simpson, and MacKinnon 1997). Several other studies have been done for elementary and middle school mathematics, the results of which were relatively similar (Davis-Dorsey, Ross, and Morrison 1991; Hart 1996). It is notable that most of these studies involved adjusting minor details in the problem to include students’ personal details, so all students still solved essentially the same problems.

While many studies have examined the personalization of mathematics problems, fewer studies have looked at personalization of problems in an engineering-specific context. In one study, researchers found that in a technology and engineering course for middle schoolers, when educators connected the material being taught to the students’ lives outside of school, the students were better able to relate to the material and could see how engineering was relevant to their everyday lives, thereby increasing student engagement with the material (Sias, Wilson-Lopez, and Mejia 2016). This is consistent with other research showing that when learners are more interested in a topic, they are more likely to engage with the task, stay focused, and put in significant effort (Hidi and Renninger 2006).

Although the majority of studies related to personalized problems focus on young children, a few studies have involved college students. In one study, 51 pre-service teachers and 50 nursing students were enrolled in the same statistics course. Researchers found that the teaching students learned more effectively when the material was framed in a way related to education compared with when it was framed in a nursing-related context, and the opposite was true for the nursing students (Ross 1983).

In summary, it seems that there has been minimal research done relating to the use of personalized problems in mechanical engineering for undergraduates. However, based on studies that used personalized problems in other contexts, there is evidence that such problems are likely to help students better engage with and learn the material and could help them see how the material is relevant to their own lives.

1.3 Conversational Coding – Knowledge Construction and Task Production

There are many ways to measure student learning and interest. One well-established method involves analysis of transcribed student conversations while working on course assignments. The turns of talk (or portions thereof) in these conversations can be classified by a code that summarizes the thought process behind the student's words. In the current study, several codes were used for conversation analysis, two of which were task production and knowledge construction.

Task production and knowledge construction are defined by Koretsky et al. (2014). Task production refers to student talk related to completing what has been assigned by an instructor, whereas knowledge construction refers to students building understanding (Koretsky et al. 2014). An example of task production is a student saying, "I'm trying to figure out how it's supposed to be written. A brief summary of what we're going to do, and a…" (Koretsky et al. 2014). An example of knowledge construction is shown below (Swenson 2018):

Ken:	That makes sense cause we made the assumption that it was zero at the bottom of that. Well, at least I did.
James:	Well, we could, to make sure that it also makes sense.

Knowledge construction and task production have been referenced extensively in education literature (Koretsky et al. 2014; Swenson 2018; Reyna and Meier 2020; Chi and Wylie 2014; Streveler et al. 2008; Hargreaves 1998).

1.4 Current Study

In the current study, an interest survey was used to obtain information on the backgrounds and interests of undergraduate mechanical engineering students enrolled in thermal fluid transport courses at Tufts University. Using this information, individualized open-ended design problems were written for each student. The goal in using these personalized problems was that students would better engage with the material and learn it more deeply.

Groups of students completed the personalized problems together throughout the semester. Along with the personalized problem, each group had to complete a generic non-personalized design problem that was used as a control for the study. Group conversations were recorded and transcribed.

As will be detailed in the Methods section, in addition to knowledge construction and task production, student conversations in the current study were coded for connections to other STEM fields, connections to the real world, connections to class content, positive student engagement, student disengagement, and distraction. This coding scheme was used to compare student discussions while working on the personalized problems to those related to the non-personalized problems and to determine if the personalized or non-personalized problems led to greater development of student understanding.

2.0 METHODS

2.1 IRB Approval and Student Participation Options

Before data collection began, the consent and experimental procedures were approved by the Tufts University Social, Behavioral, and Educational Research (SBER) Institutional Review Board (IRB). All students completed the same classwork and homework over the course of the study but needed to opt in to have data on their work collected and used. Students could individually opt in or out of having their conversation recordings saved and analyzed, having their written work saved, allowing researchers to access their final grades for the course, and allowing researchers to keep de-identified copies of their work for future studies. The course instructors were not made aware of which students consented and which did not. Students who consented to participate in the study during the first course in the study needed to re-consent to continue their participation during the second course. In the first course, 85.5% of students consented to having their recordings used for the study and 98.4% consented to having their written work used. In the second course, 85.5% of students consented to having their recordings used and 85.5% consented to having their written work used.

2.2 Experimental Procedure

Prior to the start of each course, all students were given a survey on their personal backgrounds and interests. They were allowed to opt out of answering any of the survey questions. Students were asked the following questions:

- Where are you from?
- What parts of engineering interest you most?
- What are your hobbies, interests, and activities outside of engineering?

- Is there a specific problem topic you'd like to request?
- Are there any companies (engineering or non-engineering) you're particularly interested in?
- Is there any additional information you'd like to share about yourself?

Almost 100% of the students filled out the survey. The responses were used to write two thermodynamics-, fluid mechanics-, or heat transfer-related open-ended design problems for each student, drawing on topics that the students themselves had indicated were relevant to their personal lives. The problems were intentionally ill-structured and were meant to mimic problems students might encounter while working as professional mechanical engineers. The problems were written from scratch and in such a way that students had enough details to get started on the problem but would also have to make assumptions and look up additional details using the textbook, internet, or other resources. The problems were relevant to a wide variety of topics covered in the course so that they could be given to students at several points during the semester. In some cases, if multiple students had similar interests, the same problem was used for more than one person.

The first batch of problems was to be used as part of the undergraduate core mechanical engineering course ME-0050, Thermal Fluid Systems I. The majority of the students enrolled in this course were sophomore mechanical engineering majors at Tufts University. About two thirds of the material in ME-0050 was thermodynamics, and the rest focused on heat transfer, primarily conduction and radiation. An effort was made when writing the personalized problems to align the concepts and calculations needed to solve them with course topics covered at roughly the same time as the problems were assigned. Table 1 shows a sample of student interests, personalized problems written based on those interests, and the relevant course concepts.

Table 1. Student Interests, Sample Personalized Problems, and Relevant Course Concepts

Student Interests	*Personalized Problem*	*Relevant Course Concepts*
Music Wind/brass instrument players	**Wind Instrument Tuning** At the start of orchestra and band rehearsals, the players tune their instruments. However, there is no point in doing this if the instruments are not already at the steady-state temperature they will ultimately be during rehearsal (due to wind and brass players continually blowing warm air through them), because as the instruments warm up, their tuning continues to change. You are a very busy trombone player who likes to show up three seconds before rehearsal starts, but lately the conductor has been giving you the stink-eye for being out of tune. Come up with at least 2 possible ways to speed up the warming process for your instrument. Use fluid mechanics to justify that your ideas will work to get your instrument up to temperature more quickly.	Convective heat transfer in round tubes Flow through a tube
Disney Amusement park rides	**Disney Imagineering** You are an Imagineer at Disney tasked with designing a new ride for the movie "Frozen." You want to make the ride realistically cold on the inside to simulate the frozen wasteland that Elsa creates. Figure out a design for keeping this ride cool, making sure that you minimize the amount of heat leakage. Also calculate the amount of power needed to cool the ride, and determine if it is realistic.	External flow convective cooling Power Control volumes Heat loss
Cooking Baking	**Baking a Giant Cake** As a publicity stunt, Tony Monaco has hired you to bake a single cake that will feed the entire Tufts undergrad population. He is willing to pay for a custom oven to do this. Design your cake and oven and specify a protocol for baking it such that the middle will get done without the edges getting dry or burnt. Back up your design with heat transfer analysis.	Internal convection Conduction to extended surfaces Gray body radiation
Space	**ISS Weather** The weather conditions outside the International Space Station are extreme—space is close to zero Kelvin, and unimpeded radiation flux on the sun-exposed side could cause temperatures there to soar up to more than 500 Kelvin. However, astronauts still need to live inside. Design a composite outer wall for the ISS which would reasonably insulate the astronauts enough to create livable conditions inside. Analyze the heat transfer through the wall to prove your design will work, and estimate the lowest and highest temperatures you might get inside as a result of your wall design.	Conduction through composite surfaces Space radiators Thermal resistance
Skiing Snowboarding	**Snow Making** Most ski resorts in the U.S. use snow guns to make additional snow to supplement natural snow. These machines use water and compressed air. The air forces the water to form tiny droplets, which are then expelled from the nozzle and form ice crystals, which then fall to the ground as snow. Compressed air cools as it expands, which assists with converting the water droplets into snow. Choose your favorite ski resort and the desired depth of snow for the best skiing, and use thermodynamics to determine how long it will take to cover the ski trails in that amount of snow. You may assume that one snow gun uses about 100 gallons of water per minute and that the compressor can produce 50 cfm (cubic feet per minute) of air.	Open thermodynamic systems Mass and energy conservation Phase change

The same procedure was used to develop problems for students enrolled in ME-0051, Thermal Fluid Systems II. The students enrolled in ME-0051 were mostly junior mechanical engineering majors at Tufts, and the majority had also been in ME-0050 when the first set of personalized problems was used. Approximately two thirds of the ME-0051 course material focused on fluid mechanics, with the remainder covering convective heat transfer. All personalized problems written for this study can be found in Appendix B (ME-0050 problems) and Appendix C (ME-0051 problems).

2.3 Data Collection

2.3.1 ME-0050 Thermal Fluid Systems I

The personalized problems written for ME-0050 were divided into four groups to be assigned during different weeks of the semester such that the students learned relevant problem-solving techniques and concepts around the same time in their lectures. The course instructor was regularly consulted to ensure the problems were assigned at appropriate times. Each time personalized problems were assigned, 12 to 18 students were designated as "lead students," meaning the personalized problems being used that week had been written for them. Lead students were in charge of organizing their group and turning in the completed assignment, and the plan was that throughout the semester, each student would be a lead student once. The week before a given set of problems was to be used, non-lead students were asked to sign up to work on a problem of their choice. During the sign-up process, students were given the title of each problem, but not the problems themselves. Typical groups consisted of three to four students. Students who did not select a problem were randomly assigned to a group.

The personalized problems were assigned to the students as part of their weekly homework assignments. Students were also given an additional problem, referred to here as the "generic problem," which was meant as a control to help assess the effects of problem personalization. The generic problem was an open-ended, application-focused problem relevant to current class material but intentionally did not relate to anything in which any students had indicated they were interested. Ideally, personalized problems would have been compared to generic problems that were more similar to standard well-structured textbook problems, but then the two sets of problems would have been so different that it would be difficult to tell if any differences in student discussions were actually due to personalization or something else.

All generic problems used for this study and their corresponding course concepts are summarized in Table 2. For the majority of data used for this study, the first generic problem, "Gas Specific Heats" was the generic problem that groups were given. During a given week, the generic problem was the same for all students and intentionally did not relate to topics in which the lead students had indicated interest. In most cases, the generic problems were based on problems from the course textbook but were altered to be more design-based and open-ended. Students were instructed to spend approximately one hour total working on both problems. In the homework assignment documents given to the students, for half the groups, the personalized problem was written first, whereas for the remaining groups, the generic problem was written first. Students were not given instruction on the order in which they should do the problems, but it was assumed that most groups would likely begin by working on whichever problem was written first in the assignment. The randomization of problem order was meant to mitigate the potential effects on the results of students running out of time and spending less time on the second problem or getting tired or bored before or during the second problem.

Table 2. Generic Problems and Relevant Course Concepts

Generic Problem	*Relevant Course Concepts*
Gas Specific Heats Design an experiment complete with instrumentation to determine the specific heats of a gas using a resistance heater. Discuss how the experiment will be conducted, what measurements need to be taken, and how the specific heats will be determined. What are the sources of error in your system? How can you minimize the experimental error?	Specific heats Control volumes
Firehose Tripod You have been hired by firefighters to design a tripod to hold a large hose when fighting fires. The stream of water that comes out of the hose is 5 cm in diameter. Determine what the flowrate of water out of the hose should be in order to work well for fighting a fire that is 9 meters away. Then calculate how much reaction force will be needed at the base of the tripod to keep it from moving when the hose is being used. Use fluid mechanics to support your response.	Control volumes Conservation of mass and momentum Force balance
Garden Waterfall Pump Since they know you are a mechanical engineer, your neighbors have asked you to help them design a waterfall for their garden. You need to devise a way to get water from the pool at the bottom up to the top of the waterfall, and there needs to be enough water so that the waterfall actually looks good. Design a system to do this. Include a diagram of how the pump system will work, and include any important specifications such as flow rates and dimensions. Then find a pump online and determine approximately how much power the waterfall pump will use per day. You may make as many assumptions as needed, just specify what assumptions you are making and why.	Bernoulli's Principle Head loss Power
Parachute Velocity Control You have recently gotten into skydiving. When you are skydiving, once you get close enough to the earth, you have to deploy a parachute. The skydiving part is exciting, but once you deploy the parachute, you have been getting bored since when you're falling through the air, you eventually reach one constant speed (the terminal velocity). You want to design an attachment that enables you to increase and decrease your terminal velocity as you are falling. Estimate your terminal velocity without this attachment, and then estimate the maximum and minimum terminal velocities when the attachment is being used. Use lift and drag calculations to justify your answer.	Drag
Hot Water System for the SEC You have been contracted by Tufts to design a system to get hot water to different parts of the Science and Engineering Complex (SEC). In particular, this system needs to work well during winter, when it is colder outside and most likely slightly colder than usual within the outer walls of the building and in the building in general. Estimate the wattage necessary to keep the water at a reasonably hot temperature, and determine the flow rates and pressures necessary to get the hot water to various parts of the building. Include a labeled sketch of your design, and be sure to use fluid mechanics to justify that your design will work.	Flow through a tube Convection in tube flows Head loss

Students worked in their groups to complete the personalized and generic problems. The lead student for each group was given a recording device, which they used to record their group's conversation while solving the two problems outside of class time. These recordings were then downloaded to a computer, and the ones for which not all group members had consented to their data being used were erased. Student written work was also kept for groups in which all members had consented to their written work being used in the study.

The original plan was to give all students enrolled in ME-0050 a chance to be a lead student. However, only one quarter of the personalized problems were used before Tufts University closed campus due to the COVID-19 pandemic. At the time, the IRB-approved study procedure did not include recording students if they met virtually, so no more data could be collected. Ultimately, eight usable recordings were obtained.

2.3.2 ME-0051 Thermal Fluid Systems II

The following semester, ME-0051 was run virtually due to the COVID-19 pandemic. Prior to the start of the course, IRB approval was obtained to collect data from virtual student meetings. Student groups collaborated on the generic and personalized problems over Zoom. Otherwise, the procedure was similar to the procedure used during the previous semester. Students solved the personalized and generic problems in groups of three to five and recorded the audio from their meetings. The lead students sent the recordings to the researchers, and the recordings involving students who had not consented to the study were deleted. Over the semester, 35 recordings that could be used for research were obtained.

2.4 Data Analysis

2.4.1 Development and Implementation of Coding Scheme

All eight saved ME-0050 conversations and a subset of three ME-0051 conversations were transcribed, and a coding scheme was developed to analyze the conversations. The subset of ME-0051 conversations was created by choosing one conversation from each of several different sets of problems so that a range of topics were covered by the selected problems. An effort was also made to have as many different students as possible included across the subset. Because the ME-0051 conversations used were spread across several sets of problems, students were discussing a different generic problem for each of the ME-0051 conversations.

The student conversations were coded for knowledge construction, task production, positive student engagement, student disengagement, connections to other STEM fields, connections to the real world, connections to class content, and distraction. Definitions and examples of each code are summarized in Table 3. The codes were not considered to be mutually exclusive, and there was often overlap.

The reasoning behind using the knowledge construction and task production codes in this study is described in the Literature Review section. The positive student engagement code was used because one of the goals of this study was to increase student engagement through use of personalized problems. The student disengagement code was introduced as its opposite.

Three “connections” codes were used to help determine whether using problems based on students’ interests would change the type and number of connections students made while solving the problems. Real-world connections were tracked to see how students made connections to the real world in problems that were relevant to their personal lives compared with problems that were not relevant to their personal lives but were still relevant to real-world situations. The connections to other STEM fields code was used to track instances in which students drew on STEM knowledge they had from outside of thermal fluid transport. The third "connections" code represented connections to class content, which was used to keep track of students referencing lectures, the textbook, or past homework assignments from the course (ME-0050 or ME-0051). This was significant because it was favorable to have students use the material being taught in the course when solving the problems. Finally, the distraction code was used for instances when students were not focused on the problem at hand. If students were distracted, they may have been uninterested in the problem.

To refine the codebook and establish inter-rater reliability, 67% of the conversations were coded independently by two coders with an agreement of 81.2%. The rest of the conversations were coded by one coder.

Once student conversations were transcribed and coded, a Python program was written to further analyze the coded conversations. The program was used to count the number of words and number of turns of talk to which each code from the coding scheme was applied. Separate totals were obtained for the personalized and generic problems for each group. These totals were subsequently used to compare student discussions surrounding the personalized problems to those surrounding the generic problems. The Python program and descriptive "readme" file can be found in Appendices D and E, respectively.

Table 3. Summary of Code Book

Code	*Definition*	*Example(s)*
Knowledge Construction	Students building understanding of concepts, phenomena, and situations. For this project, knowledge construction had to relate to what was being taught in the course.	A: Can someone explain what a resistance heater is then? He said a resistance heater is basically a poor what is it called compressor? A poor pump? It's basically resistance heater right? Or something like that…He said with one of the thingies when he was explaining a turbine, the compressors… B: Oh did he – I know what you're talking about. A: He was like if it doesn't work at least it's still like a crappy resistance heater. B: Future Learn heat pump vs. resistive heating. A: Yeah it's a heat pump there you go. A heat pump is a – B: We're gonna call it an over-glorified – an under-glorified heat pump. A: Under-glorified heat pump. Yeah. Sure. B: Oh it's this thing? A: Yeah yeah. B: Oh it's the coil – it's like the radiator. A: It's literally a radiator in a way. It's like it's just coils that create resistance and they dissipate heat.
Task Production	Students focusing on completing the assignment with the primary goal of turning it in without regard for furthering understanding.	"We just need to write in how we would get all these numbers." "What do they want us to do? Do they want us to draw something?"
Positive Student Engagement	Students expressing positive interest in one or more aspects of the problem.	A: Oh I love Frozen. B: Frozen II was a good one. A: Should have got an Oscar.
Student Disengagement	Students expressing that they do not like the task. Does not include instances in which students express dislike for equations or procedures that they do not end up using.	"Also little hint on your research question, having it be about biofuels doesn't make it more interesting."
Connections to Other STEM Fields	Students making connections to topics in STEM outside of thermal-fluid systems. Can include connections to other STEM classes or to real-world STEM applications.	"Thinking about the work done and I was just… the weight of the roller coaster does no work cause like it goes up and then wait -"
Connections to Real World	Students making connections to personal experiences and/or topics from the "real world" outside of school. Looking up real-world information on the internet counts towards this category.	"Something similar to like the mats in the freezer where you pass through it and you're in a totally different room." "Yeah like the Hoover Dam. They put cold water in the pipes. I think it would have taken like a couple hundreds of years if they didn't have the pipes."
Connections to Class Content	Students bringing up things that were discussed in (but not limited to) lectures, examples, the textbook, and homework assignments that pertain specifically to material taught in the course.	"So my thought is that so far in the class we've been using two different kinds of specific heats which is measured at constant pressure as opposed to measured at constant volume." "That's very similar to a lot of the problems he gives us. We've had two homework problems now with…"
Distraction	Students engaging in off-topic conversations, such as asking what time it is or discussing other classes.	A: Ok. I'd also like to make it to my next class on time. B: That is also... D: What time is it? A: It's 12:30.

2.4.2 Quantitative Analysis of Student Participation

The frequency with which each student participated in their group's conversation was also counted. This was accomplished by tallying the total words spoken by each student during the generic and personalized problem discussions. Words were counted rather than turns of talk to account for variable length in turns of talk.

To analyze equality of student participation within a group, a talk balance metric was developed that measured how evenly words spoken were distributed throughout the students. This was done to determine whether the problem type affected the dynamics of the conversation and caused students with varying levels of interest in the problem to show a different level of participation relative to the other group members.

The talk balance metric was computed as follows. N_i was the number of words spoken by student *i* during either the generic or personalized problem. N_{tot} was the sum of all N_i for a given group working on either the personalized or generic problem.

$$N_{tot} = \sum N_i \tag{1}$$

P_i was the fraction of words spoken by student *i*:

$$P_i = \frac{N_i}{N_{tot}} \tag{2}$$

The "deviation" D_i for each student in a group was computed by subtracting 1/x, where x was the number of students in the group, from P_i:

$$D_i = P_i - \frac{1}{x} \tag{3}$$

D_i can be interpreted as the deviation from equal contribution by student *i*, where "equal contribution" would be if P_i were equal to 1/x, resulting in a D_i value of 0. Note that D_i could be positive (if student *i* talked more than average) or negative (if student *i* talked less than average).

The talk balance metric (TBM), shown by equation 4, was calculated by summing the absolute values of all D_i over one group discussing one problem and dividing by the maximum possible sum of absolute values of D_i (calculated for the hypothetical case in which one student did all the talking). This value was subtracted from 1.

$$TBM = 1 - \frac{\sum|D_i|}{max\, possible\, (\sum|D_i|)} \tag{4}$$

Possible values of the talk balance metric range between zero and one. If the talk balance metric was equal to one, all students participated equally, whereas a value of zero meant that one student did all of the talking. A high value indicates a more equal conversation, whereas a low value indicates that one or two students dominated the discussion.

The D_i values for the lead student of each group were also analyzed to determine whether problem type had an effect on the lead student's participation within their group. Because the maximum possible absolute value of D_i varied depending on the group size, the D_i value for each lead student was divided by the maximum possible D_i given the size of the group (calculated from the hypothetical case in which student *i* did all the talking). This normalization enabled fair comparison across groups of different sizes. The normalized deviation is henceforth referred to as the dominance metric (DM).

$$DM = \frac{D_i}{max\, possible(D_i)} \tag{5}$$

A DM value of 1 meant that the lead student did all the talking, while a value of 0 meant that the lead student spoke the same amount as the other group members. Similar to D_i, the dominance metric could be positive or negative.

3.0 RESULTS

3.1 Words Coded Averaged Across All Groups

Figure 2 shows the number of words in the personalized and generic problems marked as each code divided by the total number of words marked as that code in both problems combined. Percentages were calculated for each group and then averaged across all groups. Distribution bars of ± one standard deviation show the spread in statistics across different groups. These distribution bars do not include any potential error due to the inter-rater reliability of 81.2% and instead just show differences between groups, which were expected. If a group had zero instances of a code in both the personalized and generic problem, that group was not included in the calculation of average percentage for that specific code. Total turns of talk were also examined, but the results were not significantly different from word count, so turns of talk data are not included in this analysis. Large differences between the personalized and generic data in Figure 2 indicate that a significantly larger percentage of words of that code occurred in one type of problem than the other. Small differences in means and large overlaps in distribution bars indicate that, on average, approximately equal words of that code occurred during personalized and generic problem conversations.

Figure 2 shows that the primary difference between students' discussions of the personalized and generic problems was that during personalized problem discussions, students devoted significantly more words to connections to the real world and positive engagement compared to the generic problems. An average of 84.1% of all words coded as connections to the real world occurred during discussions of the personalized problems. Additionally, 96.2% of all words coded as positive student engagement occurred during the personalized problem discussions.

For all other codes used (connections to class content, connections to other STEM fields, task production, knowledge construction, negative student engagement, and distraction), Figure 2 shows that there is significant overlap between the distribution bars for the personalized and generic problems. This is primarily due to the differences between various groups being greater than the differences between the personalized and generic problem discussions within each group.

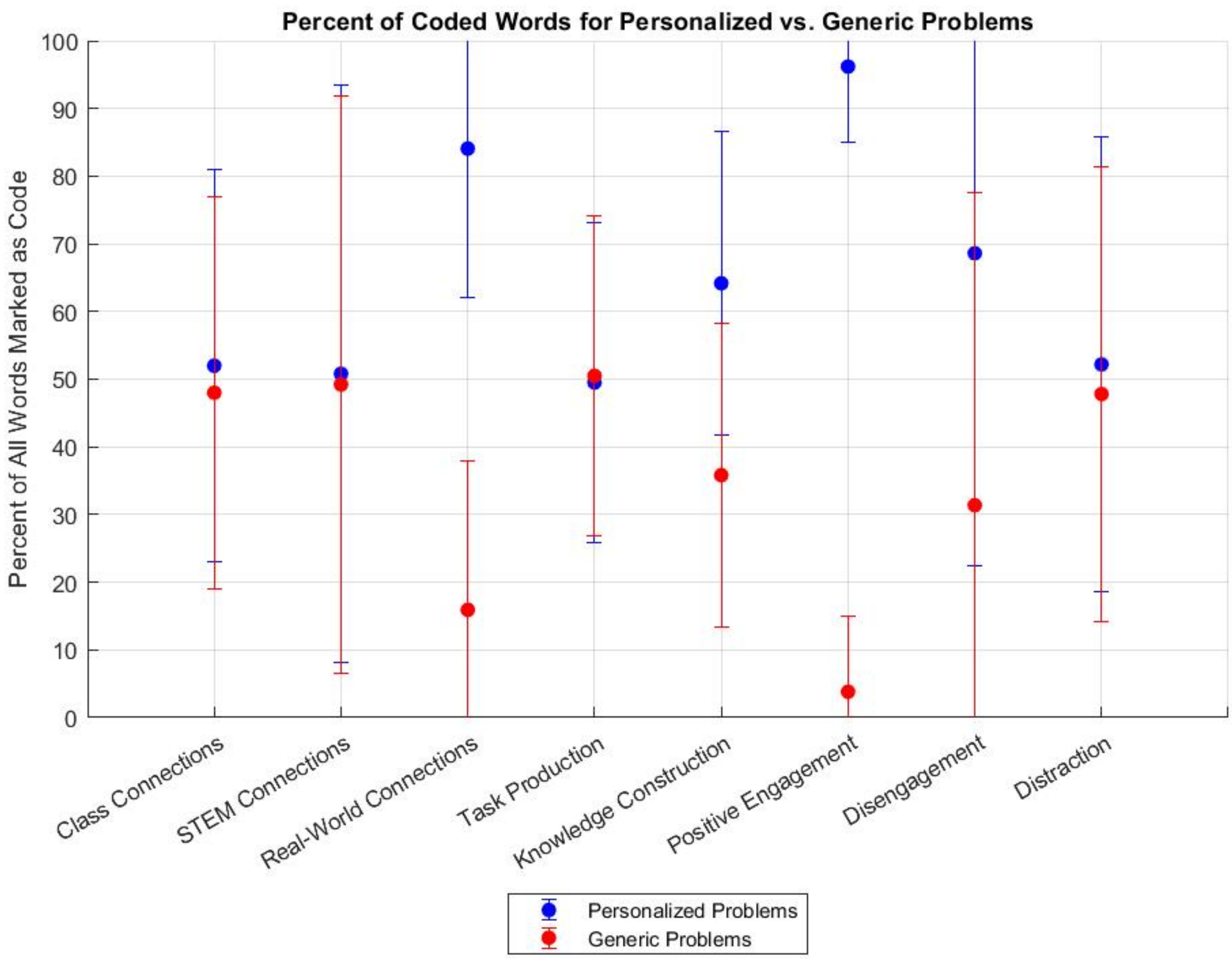


Figure 2. Words marked as each code for each problem over total words marked as each code. Distribution bars represent ± one standard deviation across different groups.

To determine the relative frequencies of each type of talk, for each group, the number of words marked as each code in a given problem was also divided by the total number of words spoken by that group during discussion of said problem. High values indicate students spent a large percentage of their time in this type of conversation, whereas low values indicate that only a few words were coded this way. These values were averaged across all groups and are shown in Figure 3.

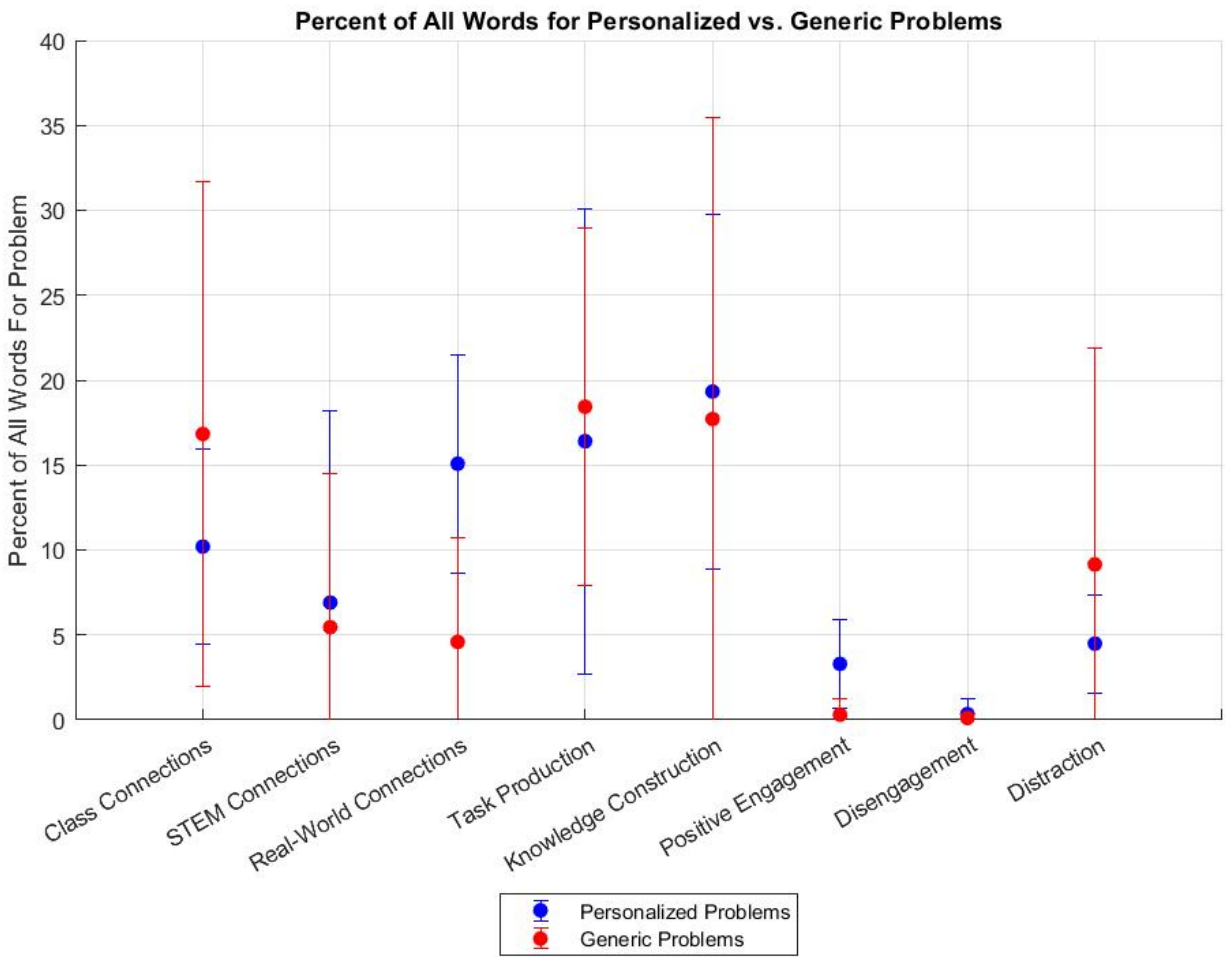


Figure 3. Percentage of words marked as each code out of all words devoted to each problem, averaged across all groups. Distribution bars represent ± one standard deviation from the mean.

Figure 3 shows that task production and knowledge construction occurred in close to equal proportions for both the personalized and the generic problems. For the personalized problems, task production made up an average of 16.4% of the problem discussion, and knowledge construction made up 19.3%. For the generic problems, the percentages were 18.4% for task production and 17.7% for knowledge construction. Connections to class content made up an average of 10.2% of the words devoted to the personalized problems and 16.8% of the generic problem words. Connections to the real world made up 15.1% of the personalized problem words but only 4.6% of the words for the generic problems. Positive student engagement and student disengagement made up the smallest portions of student discussions. For all codes, there was some overlap between the distribution bars due to differences between the groups, but a significant difference in mean values is still observable for the real-world connections and positive student engagement codes.

The data in Figure 2 and Figure 3 are not the same because on average, groups devoted more words to discussion of the personalized problems than to the discussion of generic problems. This will be discussed further in section 3.3.

3.2 Qualitative Results – Notable Excerpts from Student Conversations

This thesis focuses on quantitative analysis of student' conversations, but it is useful to include a brief qualitative discussion of a few notable examples related to positive engagement and connections to the real world. One such conversation occurred while students were working on a personalized problem about getting rid of contrails (large regions of rotating air) on a runway so that airplanes are not adversely impacted when passing through the contrails left by other airplanes. The conversation below occurred as students were brainstorming ways to prevent their idea from interfering with airplanes moving along the runway. Neither student involved in this exchange was the lead student.

Carl: This question is so interesting.

Adam: Yeah.

Carl: I was expecting like a book problem. This is nice.

In this snippet of conversation, Carl explicitly states that the problem is interesting to him, and Adam concurs. Positive engagement statements as explicit as "this question is so interesting" never occurred during discussion of the generic problems. Carl goes on to say that he had been expecting a textbook problem and makes it seem as though having a textbook problem would have been less "nice" than the personalized problem he is currently working on with his group. Therefore, here, not only does a student clearly exhibit interest in the personalized problem, but this exchange also provides evidence supporting the hypothesis that many students do not enjoy working on standard textbook problems. Furthermore, the fact that neither student involved here was the lead student suggests that personalized problems are more interesting not only to the student for whom they were originally written, but to other students in the group as well.

During discussion by another group, students were working on a personalized problem about creating a cold amusement park ride based on the movie "Frozen." Similarly to the previous excerpt, neither of the students quoted below were the lead student.

Sam: Just cool the air. That's how they freeze cement.

José: Is it really?

Sam: Yeah like the Hoover Dam. They put cold water in the pipes. I think it would have taken like a couple hundreds of years if they didn't have the pipes. More useless knowledge.

José: No, it’s useful thermodynamics knowledge.

Sam: Literally just water making cement cold. I don’t know how deep it would be. But yeah I guess it’s thermodynamics.

In this example, Sam makes a clear connection to the real world and seems to have some prior knowledge related to the creation of the Hoover Dam. Even though he is able to make this connection between the ride the group is designing and his own prior knowledge, Sam initially dismisses his statement as “useless knowledge.” José then points out that this knowledge is actually more useful than Sam had thought due to its connection to the content they are learning in class and its usefulness in relation to improving their design. Sam eventually agrees.

3.3 Words Devoted to Discussion of Personalized vs. Generic Problems

The total number of words students devoted to the personalized problems was compared to the number of words devoted to the generic problems to determine whether the use of personalized problems had an effect on the amount of time the students spent on the problems. On average, 44.1% of all total words for both problems were devoted to the generic problem with a standard deviation of 15.0%. For the personalized problems, the mean and standard deviation were 55.9% and 15.0% respectively. A t-test (α=0.05) shows that there is not a significant difference in the two means. Therefore, the data suggest that the type of problem did not significantly affect the percent of words groups devoted to each problem.

3.4 Student Participation within Groups

The talk balance metric calculation detailed in the Methods section was applied to the word count data for each student. A talk balance metric of 1 meant that everyone in the group contributed the same number of words to the conversation, while a value of 0 meant that one group member did all the talking.

The talk balance metric averaged between all groups for the personalized problems was 0.746 with a standard deviation of 0.176, and for the generic problems, it was 0.742 with a standard deviation of 0.157. This suggests that problem personalization did not significantly affect the balance of talk between group members.

The deviation values, defined in the Methods section, were also inspected for the lead students in each group to determine whether the lead students spoke more than their group members. Deviation values for each lead student were normalized by the maximum possible deviation value and the resulting parameter was referred to as the dominance metric. A dominance metric value close to 0 meant the lead student spoke exactly the same amount as the average of the non-lead students, while a dominance metric value of 1 meant the lead student did all the talking and the other students did none. The dominance metric could also be negative, which would correspond to the lead student speaking less than the average for the other students in the group.

The average lead student dominance metric value for the personalized problems was 0.103 with a standard deviation of 0.142. For the generic problems, it was 0.030 with a standard deviation of 0.133. A t-test (α=0.05) shows that there is not a significant difference in these two means. This suggests that on average, the type of problem did not significantly affect how much the lead students participated within their groups. This may also suggest that non-lead students were invested in the problems almost as much as the lead students and were making significant contributions to the problem discussions.

4.0 DISCUSSION

4.1 Student Engagement and Real-World Connections

The data suggest that when solving ill-structured, design-focused personalized problems in undergraduate thermal fluid transport courses, students exhibited more instances of real-world connections and positive engagement compared to when solving non-personalized problems that are still ill-structured and design-focused. This is evident based on the observation that students working on a problem related to their own lives or interests were more likely to verbally express their interest in and excitement for doing the problem. It is also expected that non-lead students were more engaged in the personalized problems since they signed up to work on the problem that sounded most interesting to them.

Additionally, the data suggest that when discussing personalized problems, students drew more connections between the material being taught in the course and the world around them even when both the generic and personalized problem were based on real-life scenarios. This is significant because textbook problems traditionally used in many thermal fluid transport courses often make it difficult for students to relate the material to their own lives or to any engineering work they may do after graduating. Because the personalized problems used in this study were written to relate to students' lives and interests, it is likely that students had more knowledge about the content of the personalized problems compared with the generic problems. This pre-existing knowledge likely made it easier for students to draw connections to the real world while working on the personalized problems. The students were likely also more willing to look up additional real-world information to better solve the personalized problems because this information would further their knowledge of their own special interests. Therefore, the data suggest that one way to increase student engagement and real-world connections in undergraduate thermal fluid transport courses is to include ill-structured, open-ended design problems based on students' own lives and interests.

While Figure 2 shows that more instances of positive student engagement and connections to the real world occurred during the personalized problem discussion, Figure 3 also shows that groups devoted significantly more words to connections to the real world compared to positive student engagement. This suggests that the finding that problem personalization resulted in more connections to the real world may be more significant than the finding of increased positive engagement.

4.2 Knowledge Construction and Task Production

Other research completed at Tufts University observed that while undergraduate students worked on textbook problems in a fluid mechanics course, there were significantly more utterances coded as task production than coded as knowledge construction (Swenson 2018). The assigned problems used in the study by Swenson were primarily well-structured, did not require design reasoning, and had just one correct answer. The problems were also generally unrelated to real-world scenarios. One problem provided an expression for a spatially varying velocity field and asked if it was physically possible, while another asked about water flowing out of a large container. In these problems, it was likely difficult for students to see how fluid mechanics was connected to real-world scenarios with which they were familiar. This was different from the generic and personalized problems used in the current study, as the current study's problems were ill-structured and design-based, had more than one correct answer, and related to a real-world scenario.

In Swenson's work, there was an average across groups of 26 times as many words devoted to task production as to knowledge construction. In the current study, the percentages of words devoted to task production and knowledge construction were nearly equal for both generic and personalized problem discussions (see Figure 3). This comparison suggests that the use of open-ended, ill-structured design problems that relate to real-world scenarios could lead to increased amounts of knowledge construction relative to task production regardless of whether the problems relate to student interests.

4.3 Differences Between Groups

The data plotted in the Results section is averaged across many groups. There was a significant amount of variation between groups, which resulted in the large standard deviations shown in the plots. This is likely due in part to differences in group member personalities and relationships. If some members of a group were friends, it is possible they would be more easily distracted by temptation to discuss their personal lives. If a group had one or more members who were very task production-oriented and wanted to work in a specific way, this could increase the number of instances of task production. Environment may also have played a role. In two cases, it was evident that a group was working on the problems in a location where other students outside the group were also present, and sometimes these other students distracted the group. These factors would most likely impact the group's discussion of both the personalized and generic problems, though, so the overall comparison between the two problems discussed by one group would not be affected even if the differences led to large variations between groups.

It is also likely that differences in the topics and wording of generic problems from week to week resulted in large differences from group to group. For each set of problems given to the students, everyone did the same generic problem, and five different generic problems were used over the course of the study. It was evident based on student conversations that differences in the generic problem content and wording from one week to the next had an effect on the resulting total words to which each of the codes in the coding scheme were applied. For example, in the fire hose generic problem (detailed in the Methods section), most groups analyzed motion of water from a hose using projectile motion analysis. For those groups, the generic problem discussions had a large number of connections to other STEM fields since the students were using methods from Newtonian physics. For the resistance heater generic problem, most students were initially unfamiliar with the basics of resistance heaters and thus talked through a significant amount of knowledge construction as they worked towards understanding basic concepts necessary to solve the problem. Plots for each individual group can be found in Appendices F and G. Although the plots show a large amount of variation between the groups, the general trends of more connections to the real world and positive student engagement during discussion of the personalized problems are still evident.

5.0 CONCLUSIONS AND FUTURE WORK

5.1 Conclusions

The primary goal of this thesis was to determine what effect, if any, including open-ended, design-focused personalized problems in undergraduate thermal fluid transport courses had on student interactions with the problems and the course material. Based on the eleven group conversations that were analyzed, on average, students drew more connections to the real world and exhibited more evidence of positive engagement when working on personalized problems compared with non-personalized problems that were also open-ended and design-focused. The data suggest that use of personalized problems did not significantly affect the quantity of students' connections to class content, connections to other STEM fields, task production, knowledge construction, negative engagement, or distraction. Additionally, the data from this thesis suggest that personalization of problems did not significantly impact balance of student participation within a group. However, comparison to a similar study suggests that the use of open-ended problems related to the real world (which includes both the generic and personalized problems used in the current study) may lead to increased instances of student knowledge construction compared with problems unrelated to the real world and with just one correct answer.

5.2 Suggestions for Instructors

The findings in this study suggest that inclusion of problems based on students' lives and interests is a viable way to increase student engagement and help students better see how the course content connects to the world outside the classroom. Because student interests are likely to overlap somewhat from year to year, previously written problems could be reused, which would minimize the overhead of writing a new problem for each student. To make personalization of problems simpler to implement, instructors could choose a small subset of problems (three to four) related to the current course topics from the personalized problems in Appendices B and C and have students choose one problem out of the subset to complete as part of a homework assignment. Alternatively, an instructor could have students write a personalized problem based on their own interests. Assuming there is overlap between student interests in a class, students could then choose another student's problem to solve as a separate assignment.

5.3 Future Work

The results presented in the current study focus on quantitative data averaged across many groups. With more time, the discussions of each individual group could be examined more closely. In particular, it would be interesting to see if there is a correlation between the course concepts related to each problem and the amount of connections, task production, knowledge construction, and engagement exhibited by the group. This type of data could be used to identify particular problems or topics that more effectively increase student engagement and real-world connections, which could then influence how personalized problems are used in future courses.

Due to time constraints, not all the student conversations that were recorded were transcribed and used in this thesis. Analyzing these additional conversations could lead to the discovery of other trends and could also increase the statistical significance of the claims made in the current work. Additionally, because the conversation data was partially from in-person conversations (ME-0050) and partially from virtual conversations (ME-0051), comparing the two groups of conversations could elucidate learning differences caused by shifting to the virtual modality.

APPENDIX A

Sample Assignment with Instructions

ME50 Homework 6 Open-Ended Problems

Please complete the two problems below in your group. You should spend approximately one hour total on the problems. Do not forget to record as you are working on both problems. The whole group will submit only one writeup for the problems. The group leader is responsible for this.

Due: Thursday, March 5, 2020

Lead Student: [student name]

Disney Imagineering

You are an Imagineer at Disney tasked with designing a new ride for the movie Frozen. You want to make the ride realistically cold on the inside to simulate the frozen wasteland that Elsa creates. Figure out a design for keeping this ride cool, making sure that you minimize the amount of heat leakage. Use thermodynamics to justify your design.

Gas Specific Heats

Design an experiment complete with instrumentation to determine the specific heats of a gas using a resistance heater. Discuss how the experiment will be conducted, what measurements need to be taken, and how the specific heats will be determined. What are the sources of error in your system? How can you minimize the experimental error?

APPENDIX B
ME-0050 Personalized Problems

Data collection for ME-0050 was cut short due to Tufts University closing campus as a result of the COVID-19 pandemic. The plan was to use give the students all of the below problems throughout the semester, but in the end only about a quarter of the problems were used. Problems for which data was used in this study are marked with an asterisk.

<u>*Biofuel Bus</u>
About a decade ago, Stanford University successfully tried using waste vegetable oil from the dining halls as fuel for campus shuttles (https://news.stanford.edu/news/2006/january25/biodiesel-012506.html). What if Tufts tried to do this? Plan a useful bus route around Tufts and specify the volume of fuel needed for the bus to travel this route without having to refuel. You may assume the energy density of vegetable oil is 42.20 MJ/kg or 30.53 MJ/L.

<u>Catheter Ablation</u>
Catheter ablation is a technique used to destroy a small area of heart tissue if it is sending faulty electrical signals (which can interfere with coherent beating of the four heart chambers.) The basic idea is to thread a small hot or cold probe into the heart through the major blood vessels and touch it to the bad spot until the tissue dies. Come up with a basic design for an ablation catheter, including size, wattage, and operating temperature. Consider that the doctors would like to kill a small spot of faulty tissue without damaging much of the healthy tissue around it.

<u>*Cooling Ice Cream Shop</u>
The building of Farfar's Danish Ice Cream Shop in Duxbury, MA is somewhat old and thus does not seem to have a great cooling system. As a result, sometimes the ice cream gets a bit melty even when it's still in the freezer. The temperature in the ice cream shop is to be maintained at 55°F. Estimate the dimensions of the building, use thermodynamics principles to determine the maximum heat loss the shop can have, and suggest a method for minimizing this heat loss.

<u>*Disney Imagineering</u>
You are an Imagineer at Disney tasked with designing a new ride for the movie Frozen. You want to make the ride realistically cold on the inside to simulate the frozen wasteland that Elsa creates. Figure out a design for keeping this ride cool, making sure that you minimize the amount of heat leakage. Use thermodynamics to justify your design.

<u>Exercise Analysis</u>
Many exercise machines calculate "calories burned" over time, but their estimates are generally based on the motion of the machine and do not account for calories that end up as heat rather than kinetic energy. You are designing a new system to calculate the amount of calories a person burns while exercising, which involves having a tent system over the person using an exercise machine and measuring heat loss from the tent. If you think it is necessary, you may also use sensors that monitor the person's skin temperature. Develop a specific protocol for using this tent and for determining the amount of calories the person burns.

<u>Kiln Room Cooling</u>
Most ceramic pottery is fired in kilns of temperatures ranging from around 1,800°F to 2,400°F. Understandably, when in use, a kiln will heat up whatever room it is in. Use thermodynamics concepts to develop a novel system for adequately cooling the room a kiln is in. You can choose to design insulation

for the kiln, or you can design a cooling system for the room. You are responsible for defining the dimensions of the room and for picking reasonable dimensions for the kiln if necessary. Make sure that your design is somewhat realistic to implement.

Lego Manufacturing
Legos are made using injection molding. During this process, granules of the plastic acrylonitrile butadiene styrene (ABS) are melted at temperatures of up to 450°F. This molten plastic is injected into molds, and 25 to 150 tons of pressure is applied. After about 7 seconds, the new Lego bricks are cool, and they fall onto a conveyor. What if some people are allergic to the plastic ABS? Figure out a different material to use for making Legos. Discuss how the Lego manufacturing process will have to change for this new material. Be specific about temperatures and pressures, and any other important parameters that should be used to keep this process similar to the speed of the process currently used with ABS.

Rock Climbing
Choose your favorite rock climbing route, and determine exactly what you need to eat in order to have enough energy to complete the route. To do this, you will need to research the body's efficiency when converting food into energy. You will also need to calculate how much energy you will need to complete the route. If the route is particularly long and you will take a break along the way to eat a snack, be sure to account for the weight of the food you will have to carry.

*Liquid vs. Hybrid Rocket Fuel
Hybrid rockets use a combination of solid and liquid or gaseous propellants. In hybrid rockets, a stable oxidizer is used with a solid fuel. In order to be used, the fuel needs to be vaporized. The primary difficulty with hybrids is with mixing the propellants during the combustion process. In a hybrid rocket, the mixing happens at the melting or evaporating surface. The mixing is not well-controlled and generally, a lot of propellant is left unburned, limiting the motor's efficiency. On the other hand, liquid propellants are generally mixed with oxidizer by an injector at the top of the combustion chamber which directs many small streams of fuel and oxidizer into one another. Based on reasonable efficiencies of both liquid fuel and hybrid fuel processes, estimate the weight of fuel necessary to get a specific rocket of your choice to low Earth orbit if the fuel is liquid vs. hybrid.

*Snow Making
Most ski resorts in the U.S. use snow guns to make additional snow to supplement natural snow. These machines use water and compressed air. The air forces the water to form tiny droplets, which are then expelled from the nozzle and form ice crystals, which then fall to the ground as snow. Compressed air cools as it expands, which assists with converting the water droplets into snow. Choose your favorite ski resort and the desired depth of snow for the best skiing, and use thermodynamics to determine how long it will take to cover the ski trails in that amount of snow. You may assume that one snow gun uses about 100 gallons of water per minute and that the compressor can produce 50 cfm (cubic feet per minute) of air.

Spray Cooling
Microsoft Cluster Server (MSCS) is a computer program that allows server computers to work together as a computer cluster. This drastically increases computing power. However, these server computers are all in the same room, and with the computers all performing complex calculations, everything can get pretty hot. One method of cooling computer clusters is spray cooling, in which a nozzle is used to spray water onto the computers (which, of course, are waterproofed). When the water evaporates, energy is removed from the computers, cooling them. For a particular computing application you're interested in (such as Twitter data mining or the SETI project), estimate how much energy needs to be removed per unit time to keep the computers at around room temperature. Based on this, design a spray cooling system that will allow you to make this cooling rate happen. You may assume that the computers are in a room that is 100

ft by 200 ft, one computer is 24 inches wide and 36 inches deep, and the computers can be stacked 8 high. Sketch the design of your system, and include specific critical numerical parameters such as flow rate and system dimensions. Also, assume each individual computer consumes 100 Watts of power.

*High-Altitude Airplane Engine

Gas turbine engines used in airplanes consist of a fan followed by a compressor, diffuser, combustor, turbine, and sometimes an afterburner. You are designing the engine for a high-altitude airplane. Normally, commercial planes operate best around 35,000 ft above sea level, but your plane should operate optimally at around 100,000 ft. Because of the high altitude, there will be a lower concentration of oxygen than normal, and the air entering the engine will be colder. Design a protocol for getting the oxygen up to the appropriate temperature and pressure needed for combustion. Keep in mind your solution has to be relatively light.

Drone Battery

Pick a drone you're interested in and determine the type of battery used. Based on the chemical reaction in the battery, estimate the amount of heat it dissipates. Determine an ideal location on the drone for the battery so that the heat it emits won't negatively impact other parts of the drone. Or, design a system for keeping the battery cool enough. Remember that this system will have to be very light. No matter what you choose to do, back up your design with a thermodynamics/heat transfer analysis.

Power Electric Skateboard

You are working with a skateboard company to design a new power electric skateboard. Design your own power electric skateboard that can go twice as fast as a normal electric skateboard. Outline the specifications for the motor that could be used to do this, and make sure the weight of the motor or the heat it produces won't hinder the performance of the skateboard or make the rider uncomfortable. Justify your design using a heat transfer/thermodynamics analysis.

Movie Explosion

Choose any large movie explosion, and using thermodynamics, estimate what kind of fuel was used for the explosion, how much, and where it was put to cause an explosion like the one seen onscreen. In your problem writeup, please include details about (or even better – a link to) the explosion you are analyzing. (If you can't think of any explosions, in the movie Black Panther, there is a fiery explosion when the Vienna International Center is bombed, which you can see in this video https://www.youtube.com/watch?v=EJbISNLfJJc).

Piano Tuning

Changes in humidity can easily cause a piano to go out of tune. This is because the wood from which pianos are made absorbs or releases moisture to match the humidity of its surroundings. If the wood (especially the piano's soundboard) absorbs moisture, it expands slightly, causing the pitch to rise and the piano to go sharp. The opposite is true if the piano is in a drier environment that causes the wood to lose moisture. A piano company in Orlando, Florida (which is notoriously humid), has hired you to design a new system to keep their pianos in tune when being moved from place to place. Design a way to counteract the effects of changes in humidity and temperature when the piano is moved from inside (where air conditioning makes it cool and dry) to outside (where it is hot and humid) and vice versa. Use a thermodynamics and/or heat transfer analysis to justify that your system works.

Motorcycle

Motorcycle engines use the properties of thermodynamics to transform heat into work, so they are classified as heat engines. In an engine's cylinders, fuel combustion causes the temperature of gas in the cylinder to increase, which increases the pressure and exerts a force on the piston, which then drives the motion of the motorcycle. One product of the combustion is hot air (containing heat), which is expelled during each pump of the piston. In an attempt to make motorcycles slightly more efficient (and thus better for the environment), you are working on a way to make use of this heat. Design a way to capture this heat and use it to do useful work (to help move the motorcycle?). Keep in mind that this needs to be small enough to reasonably fit on a motorcycle while still actually being helpful.

Sun Radiation While Playing Tennis

Estimate radiative heating to a person playing tennis outside on a sunny day. Propose a modification to the tennis court or what the person wears to reduce radiative heating, and justify that your idea works using heat transfer principles.

Golf Ball Manufacturing

During the manufacturing of golf balls, the spherical rubber core is centered in a dimpled metal mold, into which molten thermoplastic is injected, surrounding the core. This molten plastic entirely surrounds the core. Once the injected thermoplastic has hardened, the ball is removed from the mold, and a coating of paint is applied. You are tasked with finding the best weight for a golf ball. Choose at least 2 (or 3?) potential materials of different densities (so their weights are different), and analyze the golf ball manufacturing process using these new materials from a heat-transfer perspective. Determine if the current process will work with the new materials or if additional cooling or heating will be needed.

Baking a Giant Cake

As a publicity stunt, Tony Monaco has hired you to bake a single cake that will feed the entire Tufts undergrad population. He is willing to pay for a custom oven to do this. Design your cake and oven and specify a protocol for baking it such that the middle will get done without the edges getting dry or burnt. Back up your design with heat transfer analysis.

Staying Warm while Hiking

You are night hiking in Yosemite National Park in the winter, so it is a chilly 30°F (-1.1°C) outside. Compute the amount of body heat you lose by way of your lungs simply from breathing. The lining between the lungs and the blood is very thin, so assume the air is in direct contact with the blood. Propose a strategy (such as some new piece of clothing or heating mechanism) to ameliorate this problem, and justify it using a heat transfer model.

Body Heat Loss while Running

You decide to go for a run in the Hammond Pond Reservation in Newton, MA in January. It is a chilly 20°F (-6.7°C) outside. Compute the amount of body heat you lose by way of your lungs simply from breathing. The lining between the lungs and the blood is very thin, so assume the air is in direct contact with the blood. Propose a strategy (such as some new piece of clothing or heating mechanism) to ameliorate this problem, and justify it using a heat transfer model.

Roller Coaster Track

Choose your favorite roller coaster, and estimate the temperature of the tracks due to radiation from the sun on a sunny and on a cloudy day. If the tracks undergo too much thermal expansion, the ride may slow down due to extra friction, and this leads to dissatisfied parkgoers. Additionally, it if is exceptionally great, the thermal expansion of the tracks can lead to issues where different pieces of track connect, so it is really best to keep the thermal expansion of the tracks to a minimum if possible. Based on your previous calculations, develop a system for cooling the tracks on sunny days so they remain approximately the same temperature as on cloudy days.

Smart Soccer Watch

Your company is designing a new smart fitness watch that tracks detailed information about the soccer games the user plays. Because of the high volume of computations this piece of technology must perform it dissipates 2 Watts of energy in the form of heat. Design a system for holding the watch and dissipating the heat so that it is not too warm for the user to wear. Remember that this must all fit comfortably on the user's wrist. Justify that your design will work using a heat transfer and/or thermodynamics analysis.

<u>NASA Heat Shield</u>
Currently, NASA scientists and engineers are working on testing a prototype heat shield for the Orion spacecraft that will bring astronauts to the moon or the International Space Station. The heat shield is 5 meters in diameter, the largest one of its kind ever built. The shuttle will descend through the atmosphere at more than 25,000 mph. Develop a procedure to simulate conditions of re-entry to the Earth's atmosphere to test the heat shield prototype.

<u>ISS Weather</u>
The weather conditions outside the International Space Station are extreme—space is close to zero Kelvin, and unimpeded radiation flux on the sun-exposed side could cause temperatures there to soar up to more than 500 Kelvin. However, astronauts still need to live inside. Design a composite outer wall for the ISS which would reasonably insulate the astronauts enough to create livable conditions inside. Analyze the heat transfer through the wall to prove your design will work, and estimate the lowest and highest temperatures you might get inside as a result of your wall design.

<u>Radiation in Mercedes-Benz Stadium</u>
The Mercedes-Benz Stadium in Atlanta, GA has a pretty cool retractable roof. When it is nice and sunny out, the roof is left open, but when the weather gets bad, it can be closed. Make a recommendation to the stadium staff about whether it will be more comfortably temperature-wise with the roof open or closed when it is sunny out. Keep in mind that there will be better convective cooling if the roof is open but less radiation from the sun if it is closed.

<u>Knee Prosthetic</u>
Prosthetic knees are generally made of metal or hard plastic, which means they have very different thermal properties from human tissue. Pick a type of prosthetic knee and analyze it thermally to determine under what weather/environmental conditions its temperature would cause discomfort to the amputee wearing it. Design an add-on component that would alleviate this problem without interfering with the function of the knee.

<u>RC Car Motor</u>
The motors of remote-control cars can easily overheat. Develop a system for removing excess heat from a specific remote-control car of your choice. Be sure to plan exactly where on the vehicle your design will be placed so it doesn't hinder the performance of the car or throw it off balance. To prove that your design will work, provide a heat transfer analysis of the temperature of the motor with and without your design.

<u>Stage Lights</u>
One issue performers almost always encounter is that when they are on stage, the lights make them get very hot. Choose a specific theater with which you are familiar, and estimate a person's skin temperature while on a stage due to radiative heating from the lights. (Note that as part of this, you will have to figure out or estimate the typical wattage of the stage lights.) Propose a new lighting setup to mitigate the effects of heating from the lights while still maintaining a well-lit stage.

<u>Radiation in Boston</u>
You are planning a trip into Boston with your friends, but you want to plan ahead to know how hot it's really going to be. Yes, the weather app on your phone will give you a general air temperature, but this won't take into account radiation and reflection from all the buildings. For a season of your choice,

estimate the temperature in Boston that includes the effects of radiation directly from the sun and from the buildings that are being heated up as well. Compare a cloudy and sunny day, and determine which day would be preferable temperature-wise.

Mars Car

You are working with BMW and NASA on a new project designing an engine for a car that humans will hopefully be able to use on Mars. It is reported that the average temperature on the surface of Mars is around -63°C, and the average atmospheric pressure is around 600 Pa. Suggest changes that should be made to a regular car engine in order to ensure it will still function the same as it would on Earth. Because combustion requires oxygen but there is very little oxygen on Mars, your design will need to include some way to account for this (such as an oxygen tank). Use a thermodynamics and/or heat transfer analysis to show that your design would work.

Photovoltaics

Photovoltaics (PV) is the conversion of light into electricity using semiconducting materials that exhibit the photovoltaic effect. A photovoltaic system uses solar modules comprised of solar cells, which generate electrical power. You are tasked with installing a photovoltaic system at Tufts. Estimate the energy usage of the Tufts Medford/Somerville campus. Based on typical photovoltaic efficiencies, figure out how many photovoltaic solar panels you would need. Also specify their optimal location on campus based on how much sun various areas receive. Specify what material these panels should be made out of.

Basketball Robot

You are designing a basketball-playing robot. Because of the complex computations that this robot needs to perform to function properly, the robot's onboard computer produces a lot of heat – about 10 W. You need to make sure that this heat does not adversely affect the other parts of the robot. Choose the optimal location for the robot's computer so that it is protected but can also be kept cool. Sketch a mock-up of the robot with all the parts it would need to be able to play basketball, and show where the onboard computer would be located. Then design a system for cooling the computer so that it does not overheat, and use heat transfer and/or thermodynamics to justify your idea.

Solid Propellant Rocket

Although liquid propellant rockets are now more efficient and controllable, many rockets still use solid propellants. Solid fuel rockets have the benefit of being able to remain in storage for a long time without much propellant degradation and because they almost always launch reliably. In a solid propellant rocket, the fuel and oxidizer are mixed into a solid propellant which is packed into a solid cylinder, so there is a high risk of accidental fuel ignition, which is dangerous. Design a system for keeping the solid fuel cool and otherwise stable enough so that it won't self-ignite either when in storage somewhere or when on a rocket awaiting use. In doing so, consider the specific chemicals the fuel is made of and the conditions that would cause an unintended reaction to occur.

APPENDIX C
ME-0051 Personalized Problems

Problems were given to students as part of four homework assignments throughout the semester and are split into four sets as such. Problems for which data was used in this study are marked with an asterisk.

Set 1

*Swimming Speed Enhancement
The butterfly swimming stroke is considered by many to be one of the most difficult strokes. It is also one of the fastest. When used over longer distances, the butterfly stroke is slightly slower than freestyle, partly due to the greater physical exertion required by the butterfly. However, butterfly has the fastest peak speed. Explain why you think this stroke has the fastest peak speed. Then, design a special swimsuit or other (non-motorized) device for a swimmer to further increase the speed of the butterfly stroke so that it will always be faster than freestyle no matter the distance over which the stroke is used. Include a diagram of your design, and use fluid mechanics principles to prove that it will work.

Hydroelectric Power in Chelsea
Chelsea, MA is near several rivers, including the Mystic River, the Island End River, and Chelsea Creek. You have been contracted to develop a way to extract hydroelectric power from the one of these bodies of water. Select which river you think would be best for this and explain why. Then design a hydroelectric power system that could go on part of this river. Based on the river's usual flow, estimate how much power could be obtained from your system, and determine what percent of Chelsea's power needs could be met from this. Include a diagram of your system, and justify your responses using fluid mechanics.

Singing During COVID-19 Pandemic
COVID-19 has drastically changed how people live their daily lives. Guidelines have been created for how far apart people should stay when talking normally to each other. However, if people are doing something like singing, which takes more effort results in air (and droplets potentially carrying the coronavirus) being expelled from the lungs more forcefully, the guidelines for simply talking may not be adequate. If six feet apart is the recommendation for talking, use fluid mechanics argument to decide how far apart people who are singing should stand in order to be far enough away from any particles that may be expelled into the air by their singing.

Engineering Education
You are tasked with developing a set of demos or toys to explain conservation of mass and conservation of momentum to two groups of students, one in kindergarten, one in high school. Give details about how your demos work and what activities the students can do with them, and show the math behind the things they will observe. Assume the high schoolers know algebra but the kindergarteners don't know any math beyond counting.

Video Game Hover Suit
In the videogame Overwatch, there is a character called Pharah (seen at 1:21 in this video https://www.youtube.com/watch?v=dushZybUYnM) that has some sort of hover suit. Figure out the flow parameters for Pharah's suit, including flow rates and speeds, necessary to keep her in the air. Keep in mind that the force of the air will have to counteract the force of gravity, so you'll need to estimate the weight of the hover suit. Additionally, you should identify where on the suit the air intake will be and where the air will come out, but you do not need to worry too much about the geometry.

Sailing Camp for Kids

You are the director of a sailing camp for kids where they are learning to sail using Mercuries. You need to make sure no one goes out sailing in unsafe conditions. Use conservation of momentum to create guidelines so that the sailboats will not end up going faster than the kids can handle. Justify your guidelines with fluid mechanics.

Sailboat Racing

You are part of a design consulting firm and have been hired to make a better sail for sailboats used for racing. Use fluid mechanics to estimate the thrust on a sail under racing conditions on the Charles River. Then, suggest a design modification to a sail in order to increase the thrust without having other problems.

Hot Air Balloon

You are working for the Rainbow Ryders Hot Air Balloon Company in Arizona, which is a hot air balloon ride company. They want you to design a hot air balloon that can begin at one location and transport riders to the top of nearby Camelback Mountain. Typical hot air balloons have no built in steering system and rely on wind speed and direction to move. However, the CEO of Rainbow Ryders wants the hot air balloon to be able to run no matter the weather so the company can make as much money as possible. Develop a system that will enable the balloon to move back and forth from the mountain to its starting point in Phoenix. This system could, for example involve fans, but you should specify the positioning and flow rate of air needed for the fan(s) to do their job(s). Take into account typical wind speeds in the area, and use fluid mechanics in your design.

Hydroelectric Power in London

You have been contracted to develop a way to extract hydroelectric power from the River Thames in London, England. Design a hydroelectric power system that could go on part of the River Thames. Based on the river's usual flow, estimate how much power could be obtained from your system, and determine what percent of London's power needs could be met from this. Include a diagram of your system, and justify your responses using fluid mechanics.

Big Brother Big Sister Engineering Education

You have volunteered to run an engineering workshop for kids in the Big Brothers Big Sisters mentoring program. You want to develop a set of demos or toys to explain conservation of mass and conservation of momentum to two groups, one group of first graders and another group of high schoolers. Give details about how your demos work and what activities the students can do with them, and show the math behind the things they will observe. Assume the high schoolers know algebra but the first graders don't know any math beyond counting.

International Space Station Air Circulation

You have been hired by NASA to design a new air circulation system for the International Space Station. You don't have to worry about how the air from outside the space station will actually be filtered, but you should design a way to get the already-filtered air to flow to the different parts of the ISS. In order to keep a safe environment inside the space station, your system should remove 8 kilograms of CO_2 per day. Specify the necessary flow rates for the fans, as well as their locations.

Set 2

Dialysis

Dialysis is commonly used for people with kidney problems. This process uses a dialyzer, which is an artificial filter containing fine fibers. To remove toxins during hemodialysis, a special dialysis-fluid flows through the filter, and bathes the fibers from the outside, while the blood flows through the hollow fibers. As patients must usually undergo a dialysis treatment 3 times per week and each treatment takes 4 hours, this is a very time-consuming process. You are designing a dialyzer that works faster so patients do not have to spend so much time hooked up to this machine each week. Design a faster dialyzer, and estimate how much faster it is than a standard dialyzer using fluid mechanics. Also include a diagram of your design. (Hint: During dialysis, toxin diffusion operates in the same way as heat diffusion, so increasing area, flow speed, etc. will make the process faster.)

Making Baseball for Kids in Refugee Camps

Kids living in refugee camps generally don't have a lot to play with. In some cases, they tie plastic bags together to make balls, but these fall apart easily and don't work so well. You want to help these kids so that they can play baseball together. Design a baseball that can be made out of trash. The ball you design must work like a regular baseball – it should fly the same distance as a baseball, stand up to the drag a baseball feels, and have the same boundary layer trip (this is normal caused by the stitching on a baseball) as a standard baseball. Use fluid mechanics to show that your design will properly emulate a normal baseball.

Draper Lung Infection Test System

Invasive aspergillosis (IA) is a curable lung infection. If left untreated, this infection is deadly, but if it is properly diagnosed and treated, a patient's chances of survival increase drastically. Draper has been working with Brigham and Women's Hospital to develop a breath-based test for IA (https://www.draper.com/explore-solutions/dms-breath-analyzer). This test provides accurate results within minutes, so clinicians are able to prescribe the right treatment immediately. Draper's device is based on Differential Mobility Spectrometry (DMS) and detects trace vapors, even in concentrations as low as a few parts per million. How would such a system work? Design a process by which a person's breath would be able to be forced to travel through a system and get to the microanalyzer part of the system to actually be tested. Include a workflow for where the breath goes and what flow rates and volume of air should be expected. Also include a diagram of your design.

Measuring Pressure Drop in Arteries

You are working with a medical device company designing a stent to help patients with a stenosis in one of their coronary arteries. A stenosis prevents blood from flowing properly through a blood vessel. In order to measure the severity of this problem, a catheter is often used. The catheter is stuck into the occlusion to measure the pressure drop. However, it is possible that when this is done, the instrumentation blocks the blood flow, thus creating an inaccurate reading. A medical device company you are working for has asked you to come up with a different method for measuring the pressure drop caused by the stenosis. Be sure to use fluid mechanics concepts in your design, and include a diagram showing how it will work.

Toothbrush Manufacturing

You are working with a company to design a new toothbrush, and they have put you in charge of designing the manufacturing process. The toothbrush is going to be made through injection molding, a process in which molten plastic is injected into a mold. You need to develop a system for distributing the molten plastic from the reservoir to the molds so that you can fill at least 50 molds at once. Specify the necessary flow rates, pressures, and sizes of any pipes needed to make this happen.

*Airplane Contrails

Contrails are giant vortices left by airplanes on the runway and in the sky. If other planes pass through these, it can cause problems because it is like going through a mini tornado, and the planes are not equipped to handle such a pressure gradient. Boeing has hired you to design a device to be placed on runways to help get rid of contrails there. This could be done by moving the contrails out of the way or by stopping them altogether. Justify your design using fluid mechanics.

ELEVEN COVID-19 Protection Booth
Near the beginning of the COVID-19 pandemic, the Boston-based consulting company ELEVEN joined forces with Partners HealthCare to design the HIP Personal Protection Booth or "Hexapod." This booth creates a protective barrier between a patient and a healthcare provider and allows the healthcare provider to test a patient for COVID-19 while maintaining complete physical separation. The booth is meant to increase staff safety while also conserving personal protective equipment (PPE). It is important that the booth have proper ventilation. Design a ventilation system for this booth. This system should entirely replace the air in the booth every 2 minutes. Keep in mind that this system must bring fresh air into the booth, allow air to exit the booth, and prevent the person inside from coming in contact with any particles from a potentially sick person. Include a diagram of your design, specify all components of your system, including pressure head rise, flow rate of any fans used, and approximate dimensions, and use fluid mechanics to justify that it will do its job well.

Mass-Production Paint Pouring
Recently, random paintings created by pouring a cup full of different colors of paint onto a canvas (like this: https://www.youtube.com/watch?v=yndPwAMGEgg) have become pretty popular. You are trying to open a factory that mass-produces paintings like this using a paint robot. Figure out a protocol for pouring the paint onto fifty canvases at once. Include flow rates and any other important specifications to ensure your design will be effective. Be sure to use fluid mechanics, and include a diagram of your design.

Miss Saigon Helicopter
In some productions of the musical *Miss Saigon*, including the original Broadway production, a real helicopter is lowered onto the stage. You are working with a new production of this musical to be shown in a theater in which it has never been shown before. The director wants the blades of the helicopter to be spinning as they would spin in real life, and you've been tasked with figuring out how to make this work from a fluids perspective. Mainly, you have to make sure that the rotating helicopter blades won't blow high amounts of air onto the audience members. You also have to determine how the air that is being moved around will enter and exit the theater. Design a system to control the airflow when the helicopter is lowered onto the stage so that its rotating blades won't blow tons of air onto everyone. Include a diagram of your design, and justify that it will work using fluid mechanics.

Wind Turbines in Palo Alto
You have been contracted to install a wind turbine in Palo Alto, CA. Taking into account general weather and wind patterns in the area, you will need to select a size and type of wind turbine and suggest an ideal location. Then estimate the percentage of Palo Alto's power needs that could be generated by that wind turbine. You will likely want to use Betz's law, which states that due to geometry, the maximum efficiency of any turbine is 59.3%. Be sure to use fluid mechanics in your response.

Power Plant Wind Turbine
In many power plants, a gas turbine engine is used in the process of converting natural gas or other liquid fuels to mechanical energy, and that mechanical energy then drives a generator to produce electrical energy. You have been hired to help a power plant try to get some extra power by placing a wind turbine in the wake of the gas turbine so that the air leaving the gas turbine blows into a wind turbine. Before you install this wind turbine, though, you want to make sure that this setup will actually generate a good amount of additional power. Specify what type of gas turbine should be used, and the type and placement of the wind turbine, taking into account the fact that the air exiting the gas turbine will be hot and you do not want the wind turbine to melt. Then, using fluid mechanics, calculate how much power could be

generated by the wind turbine. You will likely want to use Betz's law, which states that due to geometry, the maximum efficiency of any turbine is 59.3%.

Hurricane Conspiracy Theory

HAARP, High Frequency Active Auroral Research Program, is a radio-technology research program funded by the US government. However, some conspiracy theorists believe that HAARP is actually a secret weather-controlling program and blame HAARP for Hurricane Katrina in 2005. What would HAARP have actually had to do in terms of flow to create a hurricane like Hurricane Katrina? Justify your response using fluid mechanics.

Set 3

Swimming Robot

You are working at a robotics company to design a robot that can swim in water to collect data on sharks. This robot needs to be as hydrodynamic as possible so that it is efficient, and you need to be able to control how fast the robot will go so it can keep up with the sharks, as well as be able to make it turn while swimming. Design a swimming robot, estimate its drag coefficient and the drag on the robot when it is moving at three different speeds (so you should have three different values for drag). Then determine how much power will be needed to make the robot move forward at each of the three speeds. Include a diagram of your robot in your response.

Bike Aerodynamics

Trek Bikes has contracted you to design an attachment for their bikes to help make the bike and rider more streamlined. This attachment should effectively reduce the bike and rider's air resistance without impeding the cyclist's ability to ride their bike as usual. Also specify what material this should be made of, and include a diagram of your design. Justify your design using fluid mechanics.

*Formula 1 Ground Effect

With Formula 1 racing cars, ground effect is when a car has an added skirt around the edge. This traps a pocket of low-pressure air under the car, thus sucking the car to the ground. However, this was eventually banned because it was quite unstable – if the car hit even a small bump, it could easily end up flipping over. However, Formula 1 is hoping to start allowing the use of these skirts once again. You have been hired to make sure this is done safely. Estimate the net force on the car resulting from the use of such a skirt. Then suggest a design modification to the skirt and/or car so that ground effect can still be used but the car is safer and more stable. (Hint: Assume inviscid flow and use Bernoulli's equation.) Justify that your estimate is accurate and that your design will work using fluid mechanics.

Race Car Wind Tunnel

Race cars need to be as aerodynamic as possible. In many cases, to test the aerodynamics of a car, a wind-tunnel is used. You have been hired by Chevrolet to analyze the air flow around their race cars. The wind tunnel you will be using to do this is an open circuit wind tunnel, where air is drawn from the laboratory environment, rather than being recirculated in the wind tunnel itself. Such wind-tunnels consist of a nozzle to accelerate the air, the test section in which the car sits, and a diffuser which decelerates the air. Based on reasonable values for air speed around the vehicle being tested, design a wind-tunnel for testing a race car. Include all necessary specifications of the different parts of the wind tunnel, such as dimensions and air speeds. Also specify the necessary power of the fan and estimate the head loss due to the vehicle. Use fluid mechanics to justify your response.

Tennis-Playing Robot

You are designing a tennis-playing robot. This robot will need to predict the trajectory of the tennis ball to ensure it goes in the desired direction over the net. This is particularly relevant if it is an extra windy day. Design a robot that can test the wind speed and direction and using fluid mechanics, determine how different wind conditions would affect the tennis ball's trajectory. Then explain how the robot could adjust its position and/or the force and angle with which to hit the ball based on how much the wind conditions are expected to move the ball when it is in the air.

Rock Climbing

You have challenged Alex Honnold to a race climbing up El Capitan in Yosemite National Park. While he might be a better climber than you, you are an engineer and he is not, so your plan is to design something to help you climb extra fast. First, estimate the force of the wind on you while climbing El Capitan. Then, using fluid mechanics, design some type of sail to redirect the wind's force on you so that it is always pushing you upwards so you can hopefully beat Alex Honnold.

Soccer-Playing Robot

You are working with a robotics company to design a soccer-playing robot. The robot needs to be able to kick a soccer ball with enough force over enough distance so that it will fly through the air all the way down the field. Your company already has a robot that works here on Earth, but with the potential for living on Mars looming in the future, you want to adjust it so it can work on the Red Planet too. Taking into account the different gravitational acceleration and different air drag that will be present on Mars, determine some scaling factor for adjusting the force the robot needs to apply to make the soccer ball travel the same distance through the air as it did on Earth. Justify your response using fluid mechanics.

Frisbee Flight

You are working with a company to make a frisbee that will stay in air longer, thus enabling it to fly farther. Suggest a design change (or changes) to help make this happen. Remember the equations for lift and drag respectively are: $L = \frac{1}{2} C_L A \rho V^2 \quad D = \frac{1}{2} C_D A \rho V^2$

Also, $C_L = C_{L0} + C_{L\&alpha}\alpha$ where α is the angle of attack. Through experimentation, it has been found that for a typical flying disc, C_{L0} is 0.188 and $C_{L\alpha}$ is 2.37. Therefore, if the ange of attach is 15 degrees, C_L would be roughly 0.62 (http://large.stanford.edu/courses/2007/ph210/scodary1/). Using fluid mechanics, show that your design change will work to keep the frisbee in the air longer than a normal frisbee.

Broom Flight

You are working with the makers of the Firebolt to improve this broom for use during Quidditch games. Estimate the drag coefficient for a person on a Firebolt broomstick at standard Quidditch speeds and suggest a design modification to the broomstick/rider system that would reduce drag. Include a diagram of the design modification, and justify that it will work using fluid mechanics.

Makeshift Kayak Paddle

You were on a solo kayaking trip on a river in the woods and managed to flip your kayak in some rapids. You are ok, but in the chaos, you lost your paddle. You are still a few hours of paddling away from civilization, so you have to find something else to use as a paddle. Determine some way to make a new makeshift paddle out of whatever you might have with you and whatever other resources might be nearby (such as tree branches). Sketch streamlines showing how the water will interact with your makeshift paddle compared to a normal kayak paddle, and compare the thrust you can get from the makeshift paddle to that of a normal kayak paddle.

Set 4

Tiny Home HVAC

You are designing a tiny home that can be used for camping adventures. You want to be able to take your tiny home on camping trips in Vermont and New Hampshire during the fall to see the foliage, but you are worried that it might get a bit too cold for comfort, as that time of year, the temperatures at night can get down to 30°F. Design a small, low-power HVAC system to keep the inside of your tiny home at a temperature no lower than 45°F. Specify what parts will be needed and how this system will be compatible with your tiny home. Use fluid mechanics and heat transfer principles to justify that this system will indeed keep the temperature at 45°F or higher.

Geothermal Heat Pump Design

Geothermal heat pumps harness renewable geothermal energy by using thermal reservoirs of water deep within the Earth for heating. Such reservoirs have temperatures up to around 370 degrees Celsius. Geothermal heat pumps use this energy by transporting room-temperature or cold liquid deep into the ground via pipes, exposing it to the hot reservoir, and carrying it back up to the surface. Imagine one of these reservoirs is discovered beneath the building where you live and design a heat exchanger system that uses the reservoir to heat your building. Sketch your system and specify the diameter, length, and material of the pipe, the flow rate, and the working fluid. Design your system such that it supplies a significant portion of the energy required for your building to operate normally.

Running Cooling

Convective cooling during running is a trade-off—if you stand completely still, you are cooled only by natural convection, which has very low h values, but the faster you run, the higher your h is, since h is positively correlated with U_∞. However, the faster you run, the faster you burn calories, generating heat that must be dissipated by convection. Find the "optimal" running speed for keeping your skin temperature low. Repeat your calculation if you're running in a headwind or a tailwind of speed typical in the Boston area. Hint: assume some percentage of your calories burned per unit time while running becomes heat that must be dissipated by convection and set this equal to $h*A*(T_s-T_\infty)$.

Convection Oven Design

You have been doing a lot of baking recently and wish that you had a convection oven. Convection ovens have one or more fans that help circulate the air in the oven, whereas in regular ovens, the only thing moving the air is natural convection. Therefore, you want a convection oven so that you can bake everything faster and more evenly. However, you don't want to spend the money on an entirely new oven since convection ovens are expensive, and you don't want to have to get rid of the regular oven you already have. Design something you can put in your regular oven that will make it function similarly to a convection oven. Specify air flow rates and estimate the power needed for any components. Also draw a diagram of your design and specify where any proposed components will go in the oven. Use fluid mechanics to justify that your design will make your oven work similarly to a convection oven.

Warming Up Trombone

At the start of orchestra and band rehearsals, the players tune their instruments. However, there is no point in doing this if the instruments are not already at the steady-state temperature they will ultimately be during rehearsal (due to wind and brass players continually blowing warm air through them), because as the instruments warm up, their tuning continues to change. You are a very busy trombone player who likes to show up three seconds before rehearsal starts, but lately the conductor has been giving you the stink-eye for being out of tune. Come up with at least 2 possible ways to speed up the warming process for your instrument. Use fluid mechanics to justify that your ideas will work to get your instrument up to temperature more quickly.

3D Printer Cooling

Carbon3D has hired you to help solve an issue they are having with some of their printers. Prints have been failing, and it seems like the problem is that the main enclosure is getting too hot. You would just remove the panels creating the enclosure to allow more cooler air to get near what is being printed, but this makes the printer too noisy since the panels also work to muffle the sound of the printer. Using typical values for the power used by 3D printers, estimate the amount of heat being created. Then develop a system to effectively cool the enclosed space while still minimizing the amount of noise the printer creates. Use calculations to show that your system will significantly cool the enclosed space, and be sure to use fluid mechanics in your response.

Dog Cooling

During the summer months, parts of North Carolina can reach temperatures around 90°F (about 32°C). Even when it is very hot outside, you still need to make sure your German Shepherds get enough exercise outdoors. This poses an issue because your dogs generate even more heat when running around, and it is already hot outdoors to begin with. Develop a device or system to help keep your dogs sufficiently cool even during the hot summer months. Sketch a diagram of your idea, and include streamlines to show how the air will flow in this system and around the dogs. Please also use convection principles to show that your design will work.

Frostbite While Skiing

You are the owner of a ski resort and people are always suing you because they got frostbite on their faces due to convective cooling while skiing. Develop a set of guidelines (in terms of air temperature and wind speed) for when your ski resort should close to avoid this problem. Do calculations that you could show in court to back up your argument that when your resort is open, there is no way a skier could get frostbite on their face. Keep in mind that when the resort is open, some people ski very slowly, and some people go down the black diamond slopes at top speed.

Tesla Battery Cooling

An extension of Tesla in Chicago has hired you to design a new cooling system for the Tesla Model S battery. The Tesla Model S uses a lithium-ion battery. These batteries need to stay between 20°C and 40°C for optimum performance. Design a system that can be used Tesla's Model S vehicles to ensure that the temperature of the battery remains in the optimal range even during Chicago's hottest days. Assume the Model S uses an 85 kWh battery pack containing 7,104 lithium-ion battery cells divided into 16 groups (called modules). Justify that your design will work using fluid mechanics and heat transfer concepts.

Surgical Robot

You are tasked with designing a miniature surgical robot that will create precise cuts in the bones around a patient's knee for knee replacement surgery. Your robot will need a high-power saw to cut bones, but it is critical that the whole system does not get too hot during sawing since the tissue around the bone could burn. Sketch the robot and design a built-in cooling system that keeps the saw blade and/or surrounding tissue cool. Use convection calculations to justify that your cooling system will work.

Temperature in Mercedes-Benz Stadium

The Mercedes-Benz Stadium in Atlanta, GA has a pretty cool retractable roof. When it is nice and sunny out, the roof is left open, but when the weather gets bad, it can be closed. When the roof is open, there is more of an opportunity for convective cooling in the stadium, but also more radiation from the sun. When the roof is closed, there is less radiation, but also less convection. Make a recommendation to the stadium staff about whether it will be more comfortable temperature-wise with the roof open or closed when it is sunny out. Also make a recommendation for placing additional fans (or some other system for added cooling) in the stadium to help increase cooling, and estimate how much this will help with keeping the temperature in the stadium comfortable. Justify your response using fluid mechanics. You should model radiation from the sun as a constant heat flus with a value appropriate for Georgia during the summer.

Water Temperature for Fish Spawning

You are going to be hosting a large fishing tournament at Turner Pond near Jacksonville, Florida in late February/early March, so you want to make sure the fish spawn early so that there are as many fully grown ones as possible by the time it's time for the tournament. largemouth bass only spawn in water temperatures above 60°F, so you want to make the water be this temperature extra early in the year. Therefore, you are designing a heating device for the pond. Design a device that will get the water up to temperature and keep it there until the weather is warm enough for the pond to naturally stay at that temperature. Include a sketch of your design, and specify any flow rates, power requirements, or anything else that may be necessary.

Jupiter Probe

You are working with NASA to design a probe that will go to Jupiter to take measurements of the Great Red Spot, which is a persistent high-pressure region in the atmosphere of Jupiter which produces an anticyclonic storm. The probe will measure wind speed at the surface of Jupiter. You need to ensure that the rover will not be ripped apart by the strong forces from the wind of the storm, so it must be sturdy and low drag. You may base your design off the design of other rovers, but you will need to make significant modifications to ensure your design will stay in one piece. You do not need to do a structural analysis, but you should justify that your design will hold up using drag calculations.

Weather Guidelines for Crew Dragon Demo-2

The Crew Dragon Demo-2 was a crewed test flight of the Crew Dragon spacecraft, which launched on May 30, 2020. When a rocket like this one takes off, it needs enough power to not only overcome the pull of gravity, but also to overcome air resistance. Using your knowledge of drag force, estimate the power needed to lift the weight of the rocket and overcome air resistance right at the moment of takeoff. Decide on weather guidelines for when a launch should be cancelled and use flow calculations to back up your answer.

APPENDIX D

Python Program Used for Coded Transcript Analysis

Quantitative Analysis of Coded Dedoose Transcript

This code takes a text file that has been exported from Dedoose after a transcript has been coded in Dedoose. Total words and turns of talk to which each code was applied are counted and exported to an Excel file. These numbers are also divided by the total words or turns of talk for the entire file. Words and turns of talk for each individual group member are also counted.

Written by Katie Melsky
April 2021

```python
# import declarations
import os
import numpy as np
import pandas as pd
import itertools



# define function that creates an array of 0 and 1 denoting whether the different
# codes appear (1) in thisLine
def func(i,k,thisLine,codes,codeNames,toremove):
    if codeNames[0] in thisLine:
        codes[0]=1
        toremove.append(i+k) # need to remove all lines that contain just code names
    elif codeNames[1] in thisLine:
        codes[1]=1
        toremove.append(i+k)
    elif codeNames[2] in thisLine:
        codes[2]=1
        toremove.append(i+k)
    elif codeNames[3] in thisLine:
        codes[3]=1
        toremove.append(i+k)
    elif codeNames[4] in thisLine:
        codes[4]=1
        toremove.append(i+k)
    elif codeNames[5] in thisLine:
        codes[5]=1
        toremove.append(i+k)
    elif codeNames[6] in thisLine:
        codes[6]=1
        toremove.append(i+k)
    elif codeNames[7] in thisLine:
        codes[7]=1
        toremove.append(i+k)
    elif 'Use in Paper' in thisLine:
        # will still need to remove the line
        toremove.append(i+k)
    return codes
    return toremove
```

```
# define students' names (followed by colon)
studNames = ['list of strings of group member names followed by :']


# load in .txt file (must be in same folder as this code file)
file = open("[filename here].txt","r")
lines = file.readlines() # list of strings
# get rid of first line since it's meaningless characters from Dedoose that aren't
# included in character count
lines = lines[1:]


# remove parent codes
parentremove=[]
for i in range(len(lines)):
    line=lines[i]
    if line.startswith('Student engagement'):
        parentremove.append(i)
# remove all lines that are "Student engagement" since it's just a parent code
for index in sorted(parentremove, reverse=True):
    del lines[index]


# list of names of codes
codeNames = ["Connections to class content","Connections to other STEM fields","Conne
ctions to real world",
             "Distraction","Knowledge construction","Positive Engagement","Disengagem
ent","Task production"]
# initialize array to store all pairs of code section start and end points
codeNums = []
# initialize array that will store indices of strings to be removed from the list
toremove = []
# initialize array that will hold all 0 1 arrays for each pair in codeNums
allCodes = []

for i in range(len(lines)):
    # reinitialize this each time
    newNums = []
    codes = [0,0,0,0,0,0,0,0]
    line = lines[i]
    if line.startswith('Codes ('):
        # get numbers from the line (these are character numbers for the codes)
        line = line.split('-')
        # pull out both numbers
        newNums = [int(line[0].split('(')[1]), int(line[1].split(')')[0])]
        # add numbers to a 2-column array
        codeNums.append(newNums)
        # store the index of the line so it can be removed later
        toremove.append(i)
        # reinitialize newNums so no issues are caused
        newNums = []

        for k in itertools.count(start=1):
```

```
            thisLine = lines[i+k]
            if thisLine[0:len(thisLine)-1] not in codeNames: # stop loop when the
# next line is not in codeNames
                break
            func(i,k,thisLine,codes,codeNames,toremove)
        allCodes.append(codes) # vector of ones and zeros to whole array

    # if the line just has the Codes in it but also has parts of student conversation
    elif "Codes (" in line:
        # find where the codes and numbers start
        codesStart = line.index("Codes (")
        # pull out just the Codes part
        subline = line[codesStart:(len(line)-1)]
        # extract numbers for codes
        subline = subline.split('-')
        newNums = [int(subline[0].split('(')[1]), int(subline[1].split(')')[0])]
        # add numbers to array
        codeNums.append(newNums)
        # remove "Codes" through ")"
        lines[i] = line[0:codesStart-1] + "\n"
        newNums = []

        for k in itertools.count(start=1):
            thisLine = lines[i+k]
            if thisLine[0:len(thisLine)-1] not in codeNames: # stop loop when the
# next line is not in codeNames
                break
            func(i,k,thisLine,codes,codeNames,toremove)
        allCodes.append(codes)


# Create and fill dataframe to store data on where different codes start and end and
# what the codes are
# names of codes (could use in extended loop thing also)
colNames = ["Start","End","Connections to class content","Connections to other STEM f
ields","Connections to real world",
            "Distraction","Knowledge construction","Positive Engagement","Disengageme
nt","Task production","Word Count",
            "Turns of Talk"]
# create dataframe to store all data
df = pd.DataFrame(columns=colNames)

# fill dataframe with data on start and end points and whether or not certain codes
# were applied
for i in range(len(codeNums)):
    numPair = codeNums[i] # pair of start and end numbers for characters
    df = df.append({'Start': numPair[0]}, ignore_index=True)
    df['End'][i] = numPair[1]
    oneCode = allCodes[i] # pull out one subset from allCodes
    for k in range(len(oneCode)):
        df[colNames[k+2]][i] = oneCode[k]
```

```
lines2 = lines
for i in range(len(lines2)):
    line=lines2[i]
    if line=="\n":
        toremove.append(i) # want to remove whole line if line=="\n"
    # remove \n from line if line contains \n
    lines2[i] = line.replace('\n','')

# delete lines that were noted to be removed (just containing \n or containing
# "Codes" or names of codes)
for index in sorted(toremove, reverse=True):
    del lines2[index]



# count words spoken by each student
studWords = np.zeros(len(studNames)) # vector to hold total words
for i in range(len(lines3)):
    line = lines2[i]
    for k in range(len(studNames)):
        if line.startswith(studNames[k]):
            # don't count "-" or student names as words
            wordsInLine = len(line.split()) - line.count(' -') - line.count(': ')
            # use line below if any group members' names have more than one word
            #wordsInLine = wordsInLine - line.count('   ') - line.count('   ')
            studWords[k] = studWords[k] + wordsInLine

# print total words by each person in group
for i in range(len(studNames)):
    print('Words by',studNames[i], studWords[i])

# combine all lines into one string to allow for character counting
lines2 = ' '.join(lines2)
#lines2 # option to show what it looks like to check that it's going ok



# count words and turns of talk and add to dataframe
for i in range(len(codeNums)):
    numPair = codeNums[i]
    piece = lines2[numPair[0]:numPair[1]]

    # number of timestamps that appear in piece (timestamps always start with [,
    # and this character is not used for anything actually spoken by students)
    timestamps=piece.count('[')
    # number of hyphens with whitespace (need to make sure these aren't counted as
# words)
    hyphens=piece.count(' -')
    # when a new person starts speaking, it's marked by their name followed by a
# colon followed by a whitespace
    talk=piece.count(': ')
    # compute word count for piece
    words=len(piece.split()) # word count
    # make it so ont counting "A: " etc. as words, not counting timestamps as words,
# and not counting hyphens surrounded
    # by whitespace as words
```

```
    words = words-talk-timestamps-hyphens
    #words = talk - piece.count('  ') - piece.count('  ')
    df['Word Count'][i]=words

    if ': ' not in piece[0:8]: # if start of coded section doesn't start at beginning
# of a turn of talk
        talk=talk+1
    if talk == 0: # turns of talk should never be zero
        talk=1
    df['Turns of Talk'][i]=talk



# Create dataframe with totals of word count and turns of talk for all codes
# create and fill dataframe with zeros to store totals for word count (row 0) and
# turns of talk (row 1)
zeroFill = np.zeros((2,len(codeNames)))
df_tots = pd.DataFrame(zeroFill, columns=codeNames)
# math to add up word count and turns of talk for each code
for i in range(len(codeNames)):
    df_sub = df[df[codeNames[i]]==1]
    # sum up word count and turns of talk and store in df_tots
    df_tots[codeNames[i]][0] = df_sub['Word Count'].sum()
    df_tots[codeNames[i]][1] = df_sub['Turns of Talk'].sum()
df_tots=df_tots.rename({0:'Word Count',1:'Turns of Talk'},axis='index')

# sum up total turns of talk and total word count
# number of turns of talk is number of : followed by a space
totTalk = lines2.count(': ')
# total words is number of "words" minus number of timestamps minus number of turns
# of talk
# also don't count hyphens as words, as they may be separated by spaces
totWords = len(lines2.split()) - lines2.count('[') - lines2.count(': ') - lines2.coun
t(' -')
# also account for names that are 2 words if necessary
#totWords = totWords - lines2.count('   ') - lines2.count('   ')

# print result
print('Total turns of talk:',totTalk)
print('Total words:',totWords)

df_tots # show dataframe with total counts for words and turns of talk



# export to excel
df_tots.to_excel("output1.xlsx")



# divide all elements of df_tots by total words and total turns of talk to normalize
# it
df_percents = df_tots
for i in range(len(codeNames)):
    # normalize first row by total words
    df_percents[codeNames[i]][0] = 100*df_percents[codeNames[i]][0]/totWords
```

```
    # normalize second row by total turns of talk
    df_percents[codeNames[i]][1] = 100*df_percents[codeNames[i]][1]/totTalk
df_percents


# output percent dataframe to Excel file
df_percents.to_excel("output2.xlsx")
```

APPENDIX E
ReadMe File for Python Code

Overview
This program takes in a .txt file that has been exported from Dedoose, the program used to transcribe transcripts. After some cleaning of the .txt file is done, total words and total turns of talk to which each individual code were applied are counted and exported as an Excel file. Additionally, total words and turns of talk for the entire file are calculated. Furthermore, total words spoken by each individual student are counted and displayed.

Description of Each Cell
Bold text indicates something that must be changed between each use of the program.

Import necessary packages.

Define function *func(i,k,thisLine,codes,codeNames,toremove)*. *i* is the current section of transcript being looked at, defined by a pair of numbers indicating start and end characters of the code in the whole transcript. *k* is added to *i* until a line consisting of just a newline character '\n' is reached. Each line after the ith line (the *i*+*k*th line) is examined, and it is determined if this line, called *thisLine*, matches one of the codes defined in the list of strings called *codeNames*. If the *i*+*k*th line is in *codeNames*, a 1 is put in the corresponding location in the vector *codes* rather than a zero. Each element in *codes* corresponds to a code in *codeNames*. This function returns *codes*, which is a vector with the same length as *codeNames* containing just 1s and 0s. It also returns *toremove*, which is a vector containing the indices of elements in the list of strings that is the entire transcript. Lines containing only code names are eventually removed so that number of characters in the transcript can be counted properly. Currently, the length of *codeNames* is hard-coded into the function, so this would need to be changed if the total number of codes is different from eight. Additionally, the code 'Use in Paper' was used for this project, but it is not necessary for any sort of analysis, so this would need to be changed if the 'Use in Paper' code is not being used for a different project.

A list of strings containing the names of each group member followed by a colon is created. **This must be changed to reflect the names of the students in a particular group.** For example, studNames could be ['A:','B:','C:','D:'].

The file containing the transcript (in the form of an unedited text file directly downloaded from Dedoose) is opened. **The user is responsible for manually changing the file name here.** For the purposes of comparing a generic and personalized problem, the transcript for a group's entire conversation must be divided into personalized and generic problem discussions within Dedoose before being exported. Then these files must be run through the program separately.

The file is read in such a way that turns it into a list of strings, and it is given the name *lines*. It should be noted that between each line of text, there is a newline character '\n'. This may or may not change depending on the spacing used in the file that is exported from Dedoose.

Indices of lines containing names of parent codes are stored in *parentremove* and subsequently removed since the names of the child codes also appear in *lines*, which is at this point a list of strings, where each element in the list is a line from the transcript, a newline character, or the name of a code that was applied to a nearby portion of the transcript.

codeNames is a list of strings defining the names of codes used in the project. Capitalization must match what was used in Dedoose. *codeNums, toremove,* and *allCodes* are all initialized as empty arrays. *codeNums* is an array of pairs of numbers reflecting the character numbers in the transcript where each section to which a code was applied starts and ends. *toremove* is an array containing the indices of elements in the transcript list of strings that are not actually part of the transcript. This includes 'Codes' followed by a pair of numbers in parentheses, lines containing only code names, and lines containing only the newline character '\n'. *allCodes* is an array containing vectors of 0s and 1s, each of which corresponds to a pair of numbers in *codeNums.*

The for loop iterates through all elements in the list of strings defined by *lines*. During each iteration of the loop, *newNums* is reinitialized as an empty array. *newNums* will be an array containing the newest pair of numbers defining characters where a coded section starts and ends. Additionally, *codes* is reinitialized as an array of zeros with the same length as the number of codes being used in the project. *line* is the current line being examined, which is the *i*th element in *lines*. If *line* begins with 'Codes (', it means that all that *line* contains is 'Codes' and two numbers inside parentheses and separated by a hyphen '-'. If this if statement is true, the current *line* is split up using the '-' between the two numbers, and then one number is extracted from each of the two pieces of *line* that have been split up. These two numbers are put into an array *newNums*, which is then appended to *codeNums*. Additionally, since in this case *line* contains only information that is not part of the actual transcript, its index is added to *toremove*. *newNums* is then reinitialized to an empty array.

Within the if statement, another for loop is used, which continues to loop through the *i*+*k*th lines (*thisLine*) that follow *line*. This loop continues adding to *k* until *thisLine* is not equal to the name of a code. Provided *thisLine* is equal to the name of a code, the function *func* is called (described above). Once the *k* for loop is broken out of, *codes*, a vector of 1s and 0s, is appended to *allCodes*.

If *line* does not start with 'Codes (', it is still possible that the line might contain 'Codes (' and character numbers somewhere else in the line (likely near the end). This is what the elif statement is used for. If 'Codes (' is somewhere else in *line*, the part of the string that contains 'Codes' and the associated character numbers is pulled out, starting with the index of *codesStart*. This *subline* is then split up in the same fashion as was done in the if statement above. *newNums* is again appended to *codeNums*. Additionally, the portion of the line containing 'Codes (', the character numbers, hyphen, and the ')' is removed from *line*, and the line is then replaced back into *lines*. Essentially the same for loop is used here as was used in the above if statement. The final result is *codeNums*, which is an array of pairs of numbers, *toremove*, which is an array of indices of strings to be removed from *lines* (though *toremove* is not yet complete), and *allCodes*, which is an array containing vectors of 1s and 0s, where the 1s indicate that the corresponding code in *codeNames* was applied to the section of transcript defined by the pair in *codeNums*.

In the next cell, a dataframe is created to store the start and end characters for each coded section, the names of the codes, and the word count and total turns of talk for that section. *colNames* is a list of strings containing column names to be used for the dataframe. This must be changed to reflect different code names. *codeNums* is used to fill the first two columns of the dataframe *df*. The columns headed by code names are filled with 1s or 0s. This is done using *allCodes*. A for loop iterates through all pairs in *codeNums*, which also have corresponding vectors in *allCodes*, so the *i*th vector is also extracted from *allCodes* and called *oneCode*. Each entry in *oneCode* is placed in the appropriately corresponding column in the dataframe *df*.

lines2 is set equal to *lines* (it is given a different name in order to leave *lines* mostly intact for any debugging purposes). All elements in *lines2* that contain only the newline character '\n' are appended to *toremove*. Additionally, instances of '\n' in *lines2* are removed. Then, the numbers stored in *toremove* are used to remove all those lines from *lines2*.

studWords is initialized as an array of zeros with the same length as the number of students in the group. A for loop goes through each element in *lines2* and depending on which student's name the line begins with, counts the total words spoken by that student and stores it in the appropriate location in *studWords*. **If there are any students in the group with names that are more than one word long, *wordsInLine* is adjusted so that the extra words in a student's name will not be counted as words spoken by that student.** Student names and the total words spoken by each student are then printed.

All the strings in *lines2* are joined into one long string, with a whitespace being placed between each of the elements of *lines2* that are being combined.

This cell counts the total words and turns of talk in each coded section defined by a pair of character numbers and adds that information to the dataframe *df*. A for loop iterates through all pairs of character numbers stored in *codeNums* and uses those indices to pull out a *piece* of *lines2* to examine. *timestamps* is the number of timestamps found in *piece*, which is determined by the number of '['. The square bracket character is used only for timestamps and for '[inaudible]' so anything within a square bracket should not be included in the word count. *talk* is the number of turns of talk in *piece*, measured by the number of colons followed by spaces. *hyphens* counts the number of hyphens found in *piece*. **Similar to when words by each student were counted, if there are any students with multi-word names, the number of instances of those multi-word names are subtracted from *words*.** If a colon followed by a whitespaces does not appear at all in *piece*, it means that in Dedoose, the section that was coded only involved one group member's turn of talk but did not include the very beginning of that line where the particular student was identified. If that is the case, one is added to *talk* to account for that being the case. t*alk* and *words* are stored in the 'Turns of Talk' and 'Word Count' column in the dataframe *df*.

The next cell creates a dataframe *df_tots* containing the total turns of talk and word count for each code. First, a dataframe *df_tots* filled with zeros is created with the columns defined by *codeNames*. *df_tots* is made to have two rows, as the top row will be for word count, and the second row for turns of talk. Next, a for loop is used to sum up total word count and turns of talk for each code and store them in *df_tots.* This loop iterates through all entries in *codeNames* and creates a new dataframe *df_sub* consisting of all the rows of *df* where the entry in the column defined by *codeNames[i]* is equal to 1 since that indicates that *codeNames[i]* was applied to the given section of the transcript. The total word count and total turns of talk are calculated from *df_sub* and stored in the appropriate location in *df_tots*. The row indices of *df_tots* are then renamed to be 'Word Count' and 'Turns of Talk'.

The total turns of talk and total words in the entire transcript are calculated and stored in *totTalk* and *totWords*. For *totTalk*, the number of instances of ': ', which indicates the presence of a student beginning to speak, in *lines2* are counted. *totWords* is calculated by first splitting up *lines2* by whitespaces. Then the total number of timestamps (indicated by the presence of '['), total turns of talk (so student names defining the beginning of a new turn of talk are not included in word count), and total number of hyphens with whitespace before are subtracted from this to ensure that only words spoken by students are counted in *totWords*. Finally, *totTalk* and *totWords* are printed, and *df_tots* is displayed.

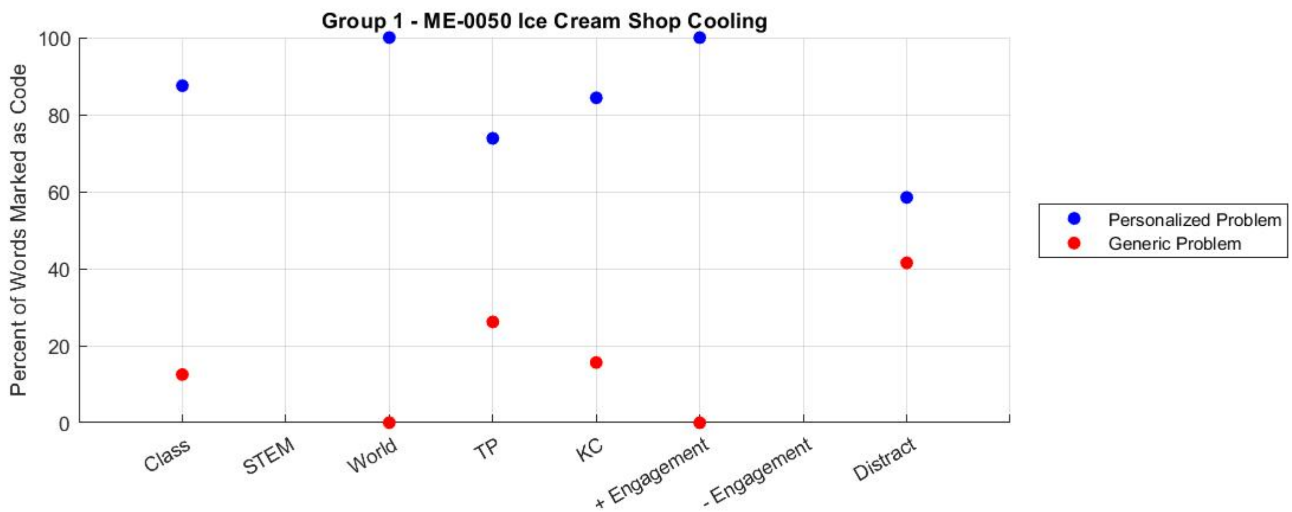
df_tots is exported to an Excel file.

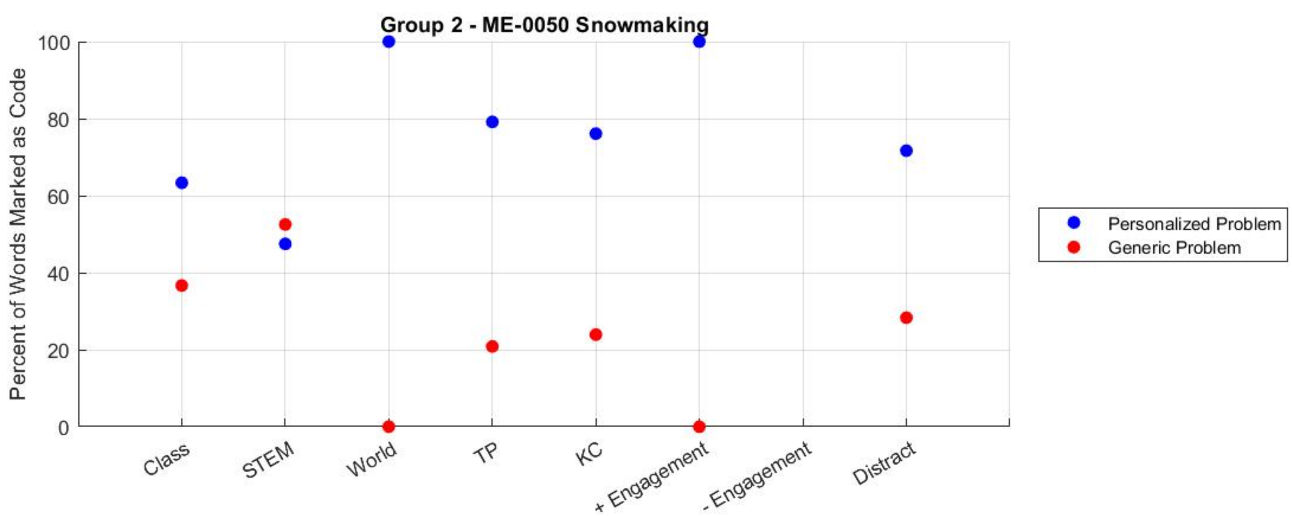
A new dataframe called *df_percents* is created based on *df_tots*. *df_percents* normalizes the word counts for each code by the total word count for the entire transcript and normalizes the turns of talk by the total turns of talk in the transcript. The result is a dataframe *df_percents* containing percentages of total words and total turns of talk.

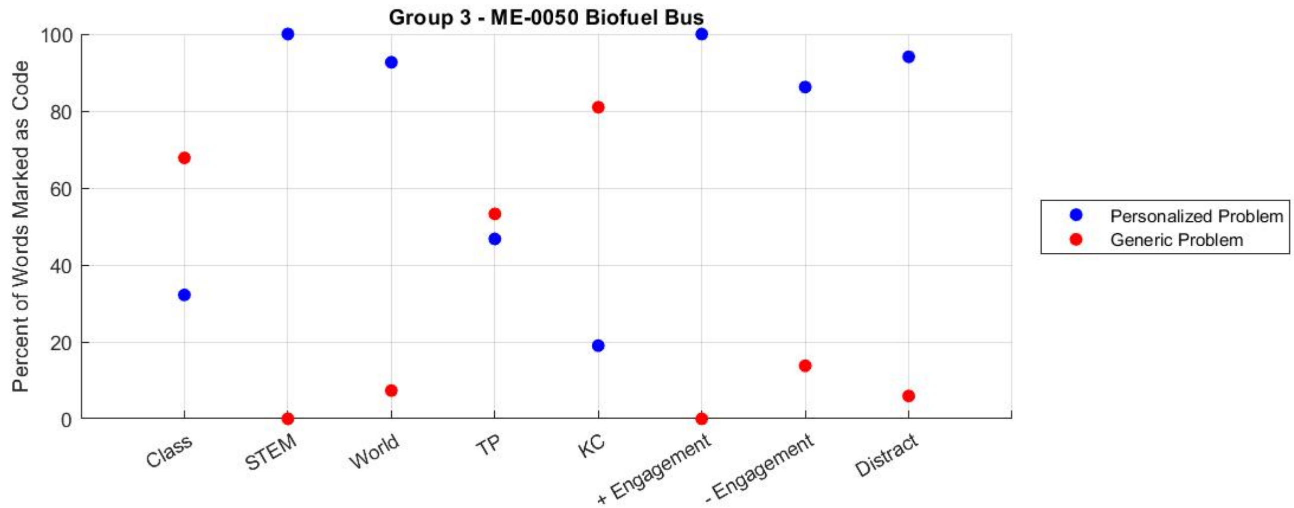
Finally, *df_percents* is exported to an Excel file. The name of the Excel file should be changed by the user so that it is easy to find the file once it has been created.

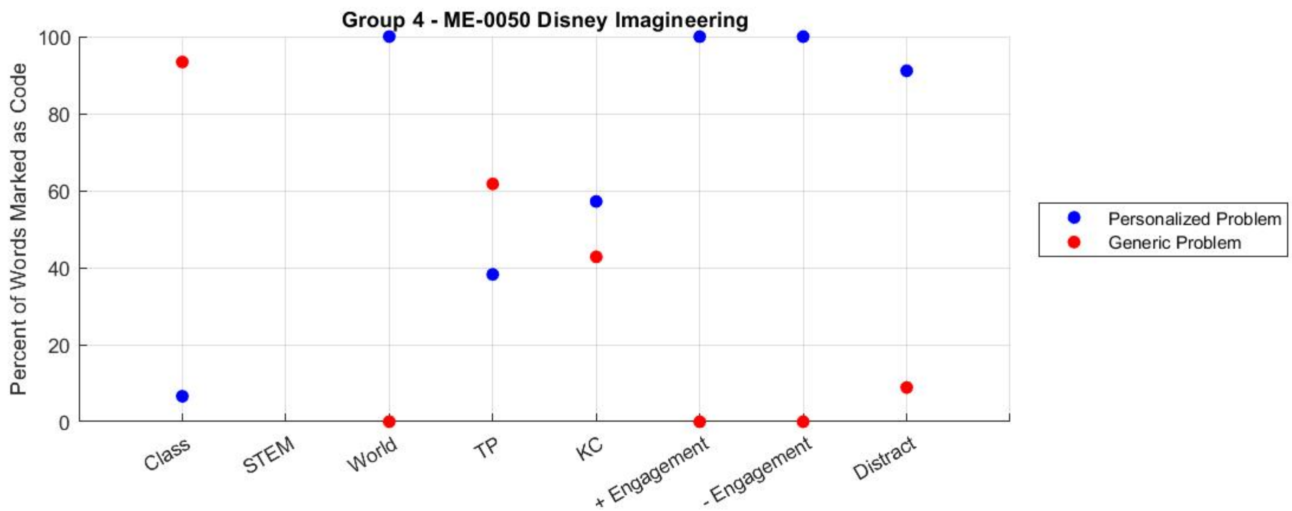
APPENDIX F
Plots for Individual Groups – Percent of Words Marked as Each Code

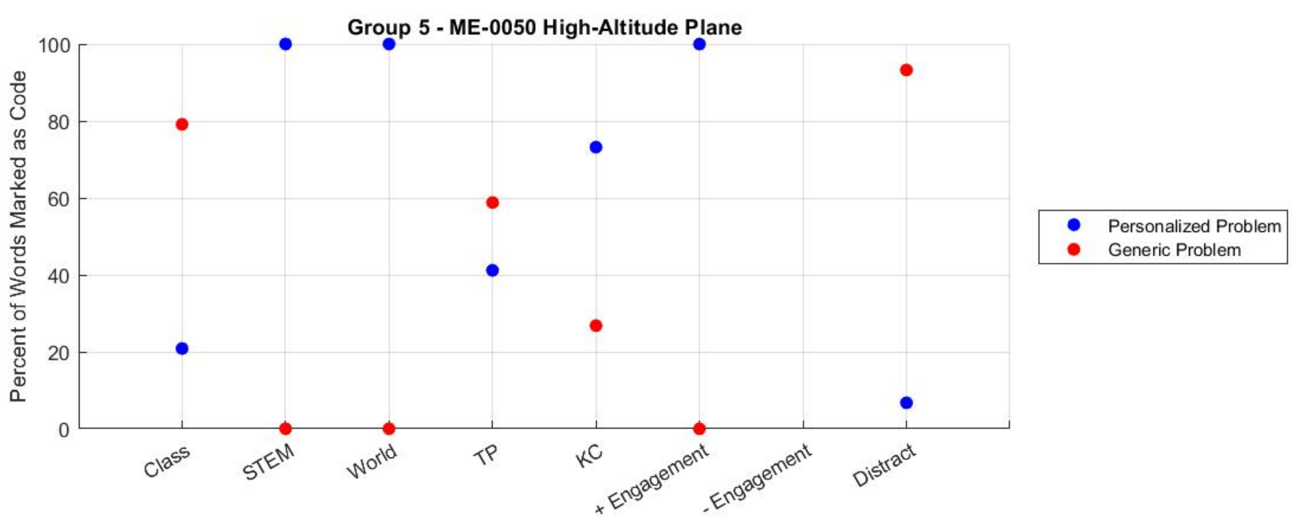
Each plot shows the percent of words in one problem marked as a given code out of all words marked as that code across both the personalized and the generic problem. For cases where a group had no instances of a code in both the personalized and generic problems, no data is plotted for that code.

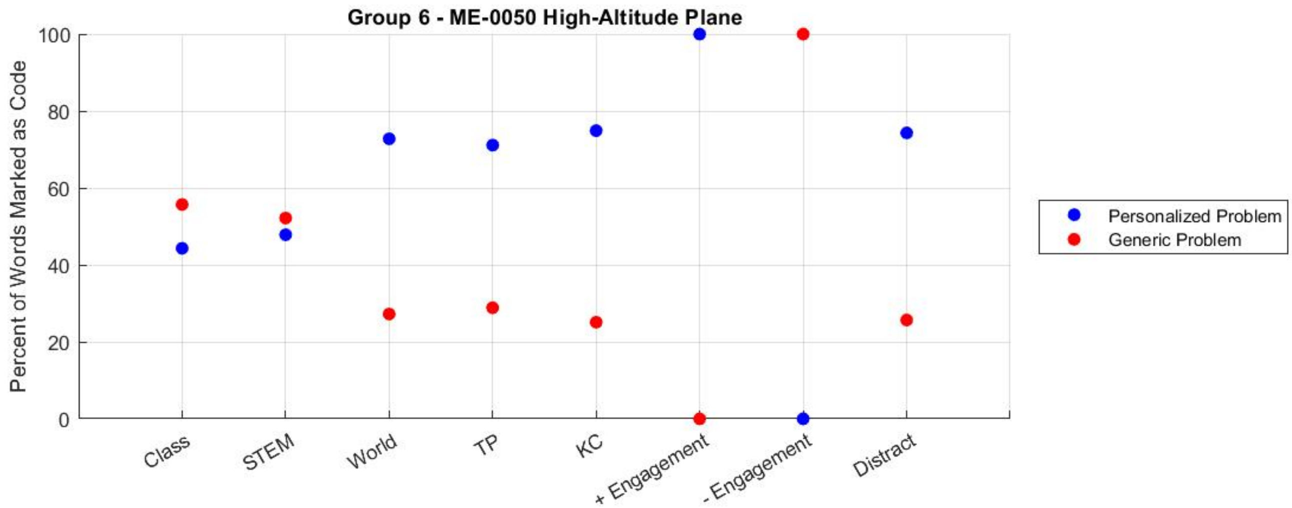


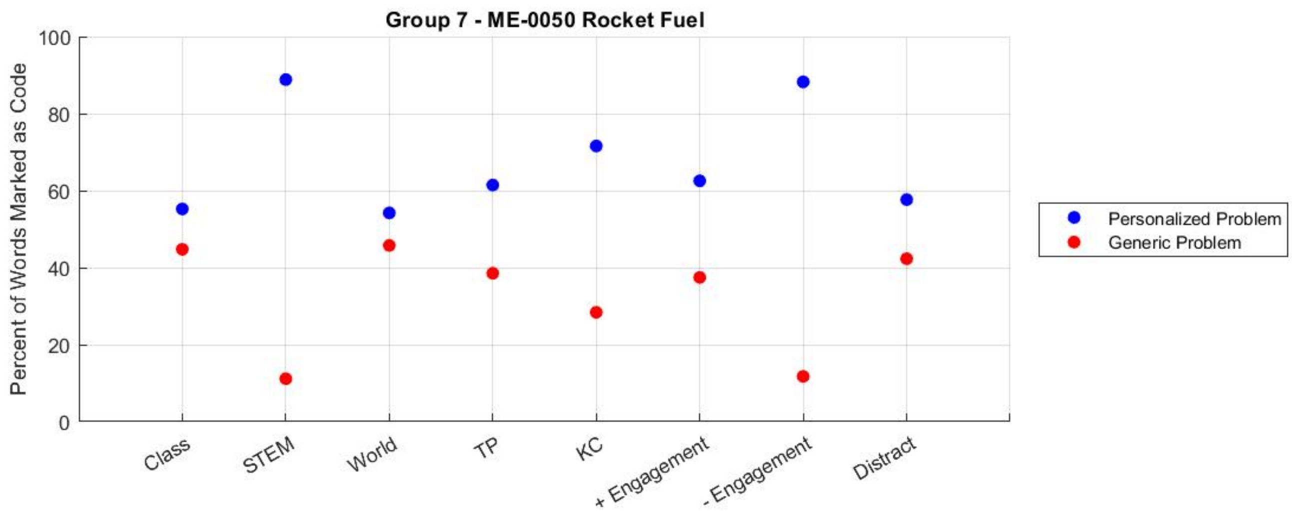


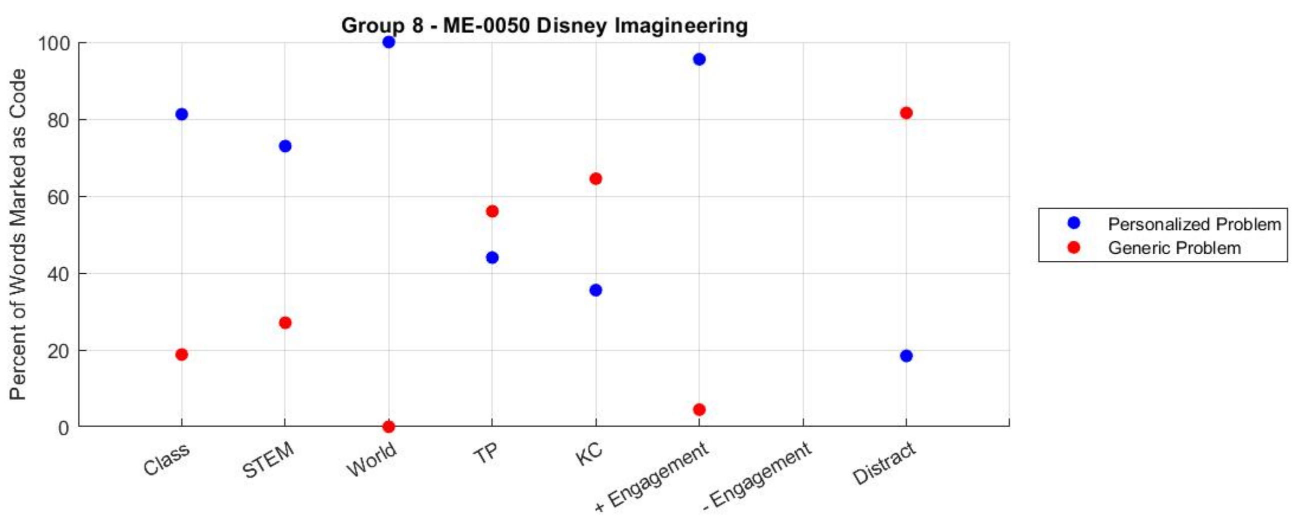

Group 3 - ME-0050 Biofuel Bus
Percent of Words Marked as Code
100
80
60
40
20
0
Class
STEM
World
TP
KC
+ Engagement
- Engagement
Distract
Personalized Problem
Generic Problem

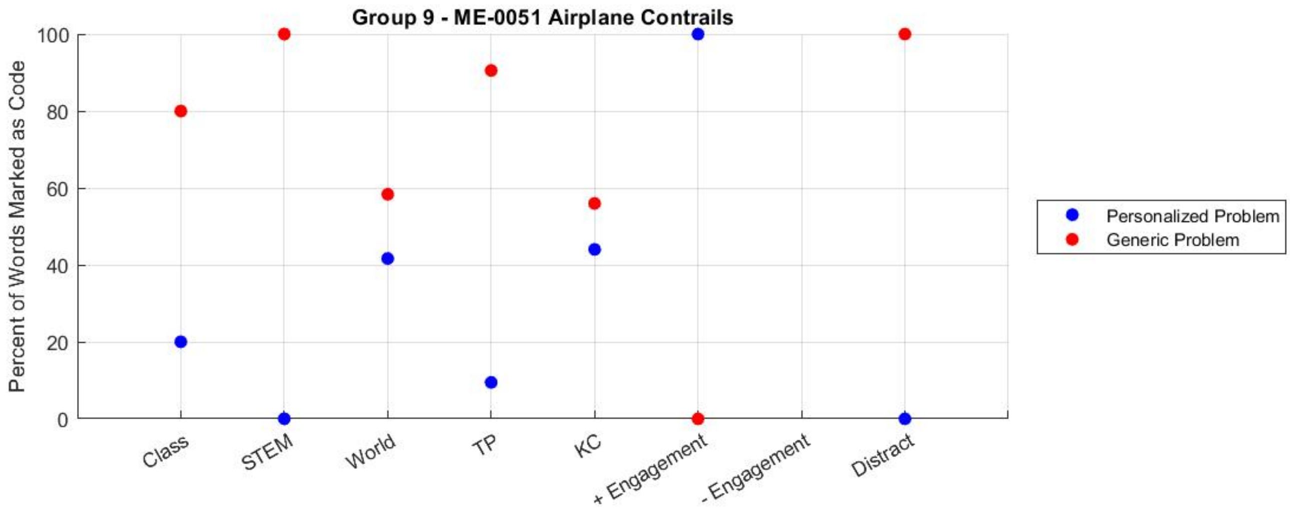

Group 4 - ME-0050 Disney Imagineering
Percent of Words Marked as Code
100
80
60
40
20
0
Class
STEM
World
TP
KC
+ Engagement
- Engagement
Distract
Personalized Problem
Generic Problem

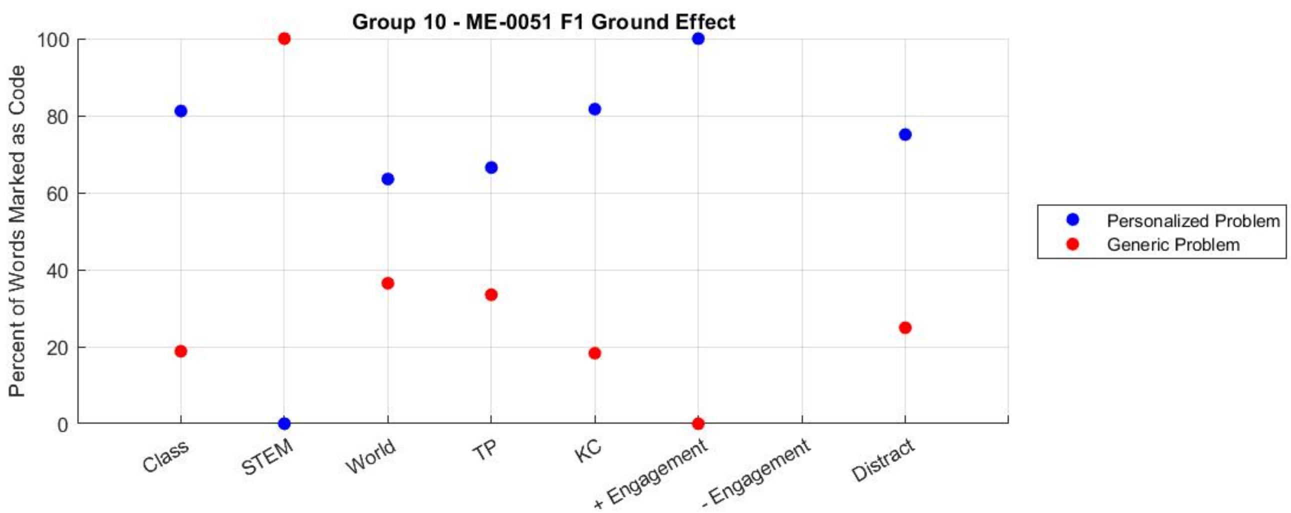

Group 5 - ME-0050 High-Altitude Plane
Percent of Words Marked as Code
100
80
60
40
20
0
Class
STEM
World
TP
KC
+ Engagement
- Engagement
Distract
Personalized Problem
Generic Problem

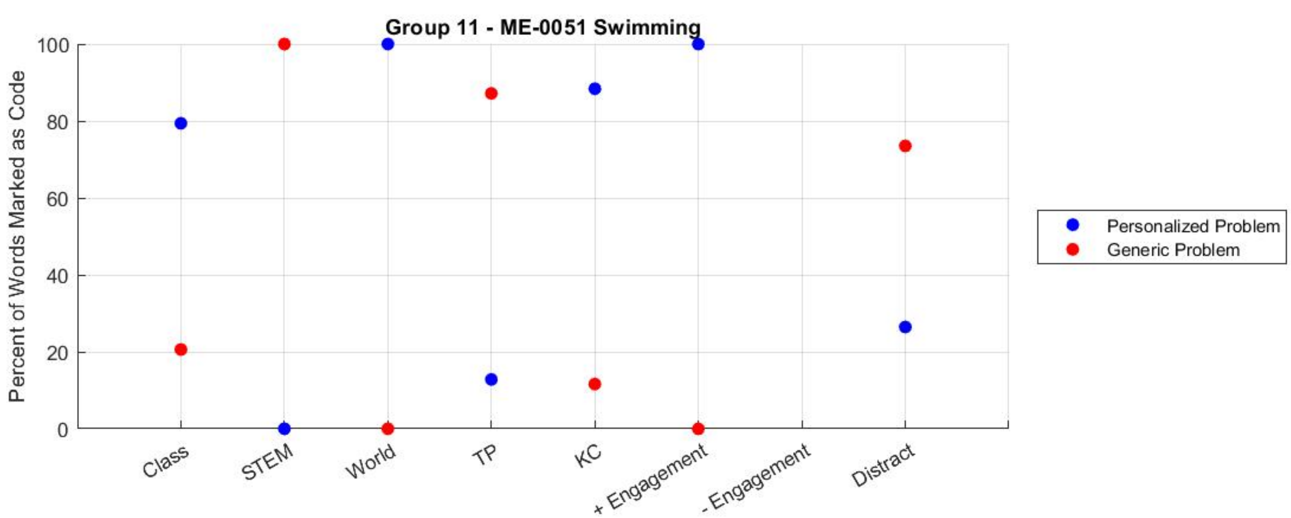

Group 6 - ME-0050 High-Altitude Plane
Percent of Words Marked as Code
Class
STEM
World
TP
KC
+ Engagement
- Engagement
Distract
Personalized Problem
Generic Problem


Group 7 - ME-0050 Rocket Fuel
Percent of Words Marked as Code
Class
STEM
World
TP
KC
+ Engagement
- Engagement
Distract
Personalized Problem
Generic Problem


Group 8 - ME-0050 Disney Imagineering
Percent of Words Marked as Code
Class
STEM
World
TP
KC
+ Engagement
- Engagement
Distract
Personalized Problem
Generic Problem


Group 9 - ME-0051 Airplane Contrails
Percent of Words Marked as Code
Class
STEM
World
TP
KC
+ Engagement
- Engagement
Distract
Personalized Problem
Generic Problem

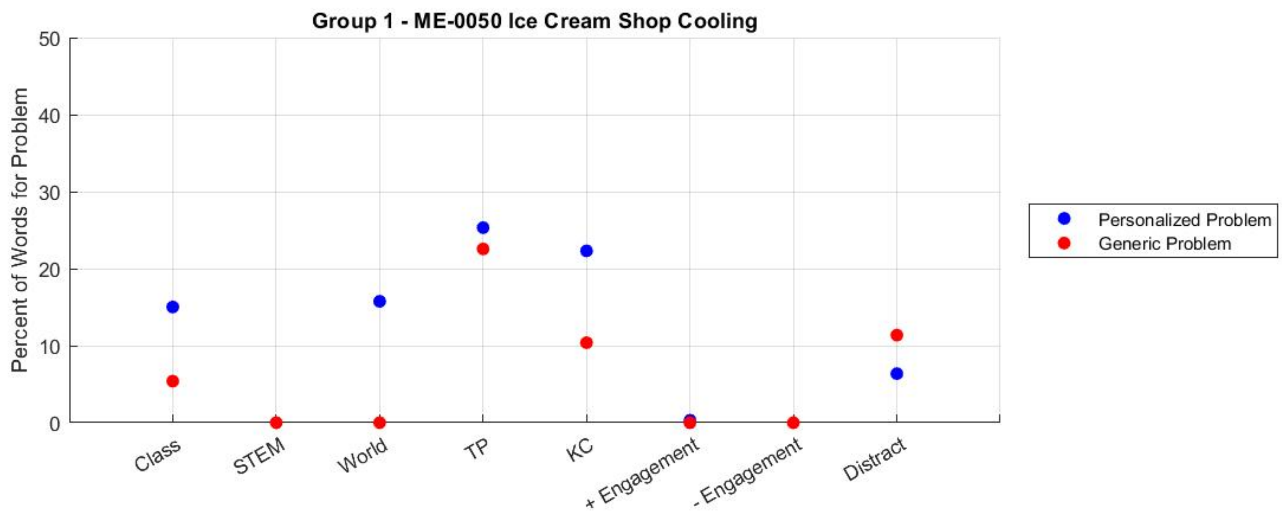

Group 10 - ME-0051 F1 Ground Effect
Percent of Words Marked as Code
Class
STEM
World
TP
KC
+ Engagement
- Engagement
Distract
Personalized Problem
Generic Problem

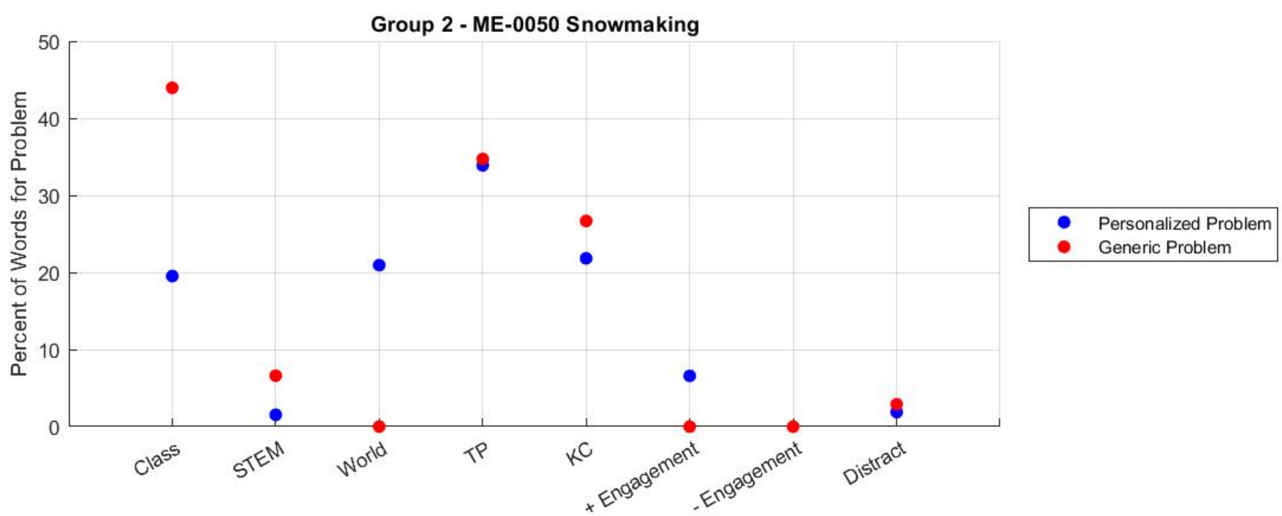

Group 11 - ME-0051 Swimming
Percent of Words Marked as Code
Class
STEM
World
TP
KC
+ Engagement
- Engagement
Distract
Personalized Problem
Generic Problem

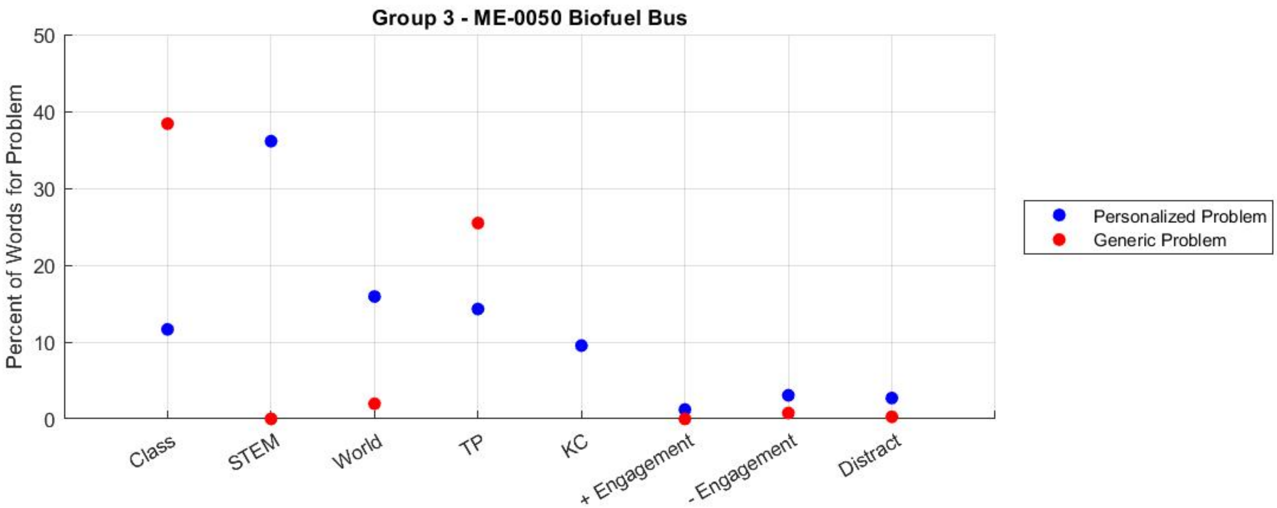
APPENDIX G

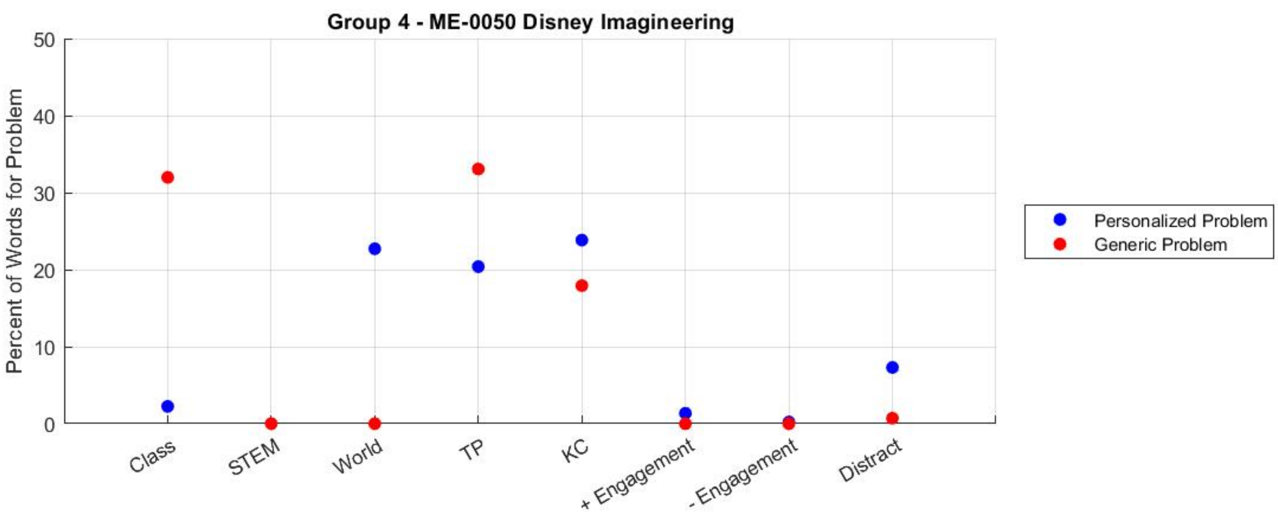
Plots for Individual Groups – Percent of All Words for Each Problem

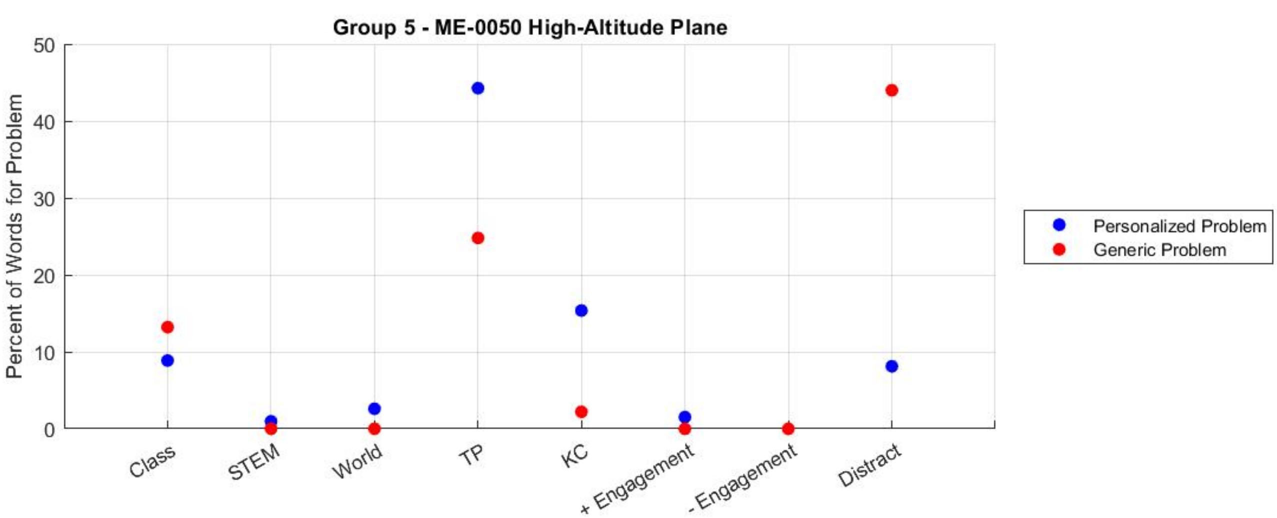
Each plot shows the percent of words in either the personalized (blue) or generic (red) problem marked as a given code out of all words the group devoted to that problem.

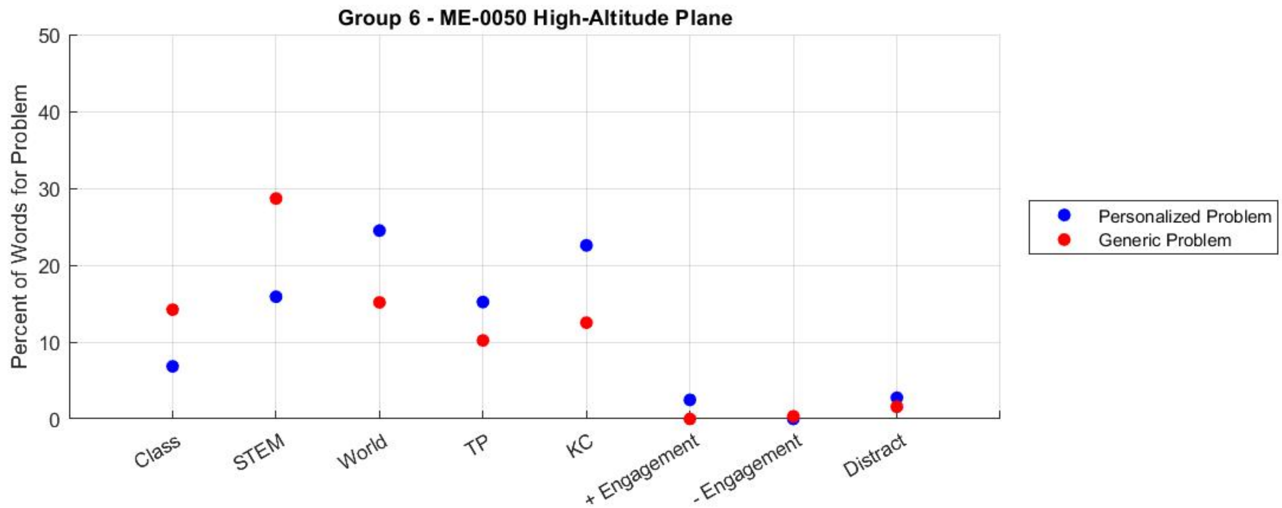


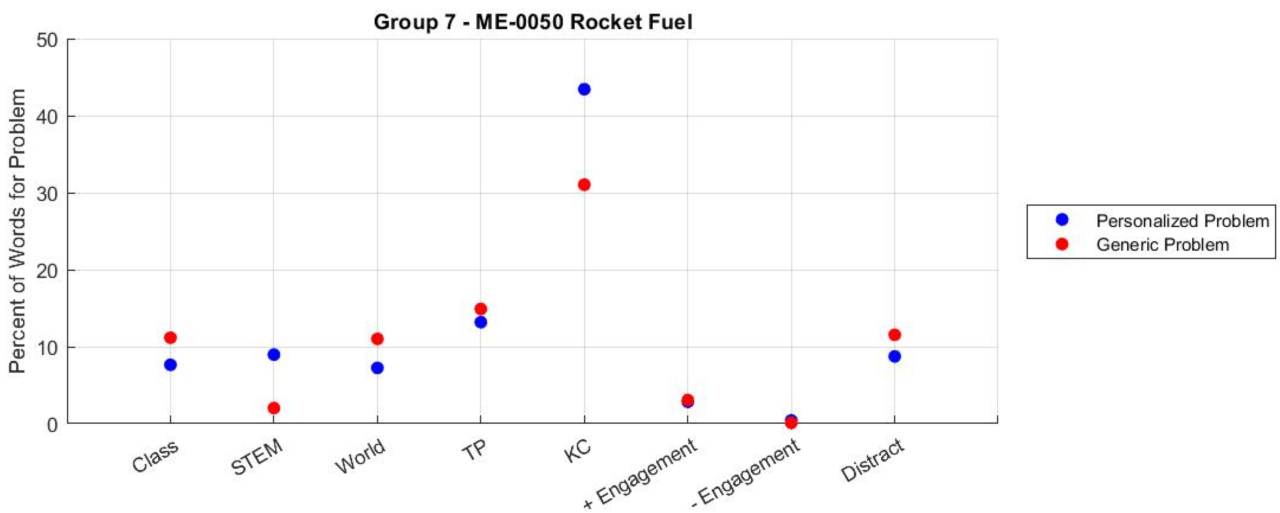


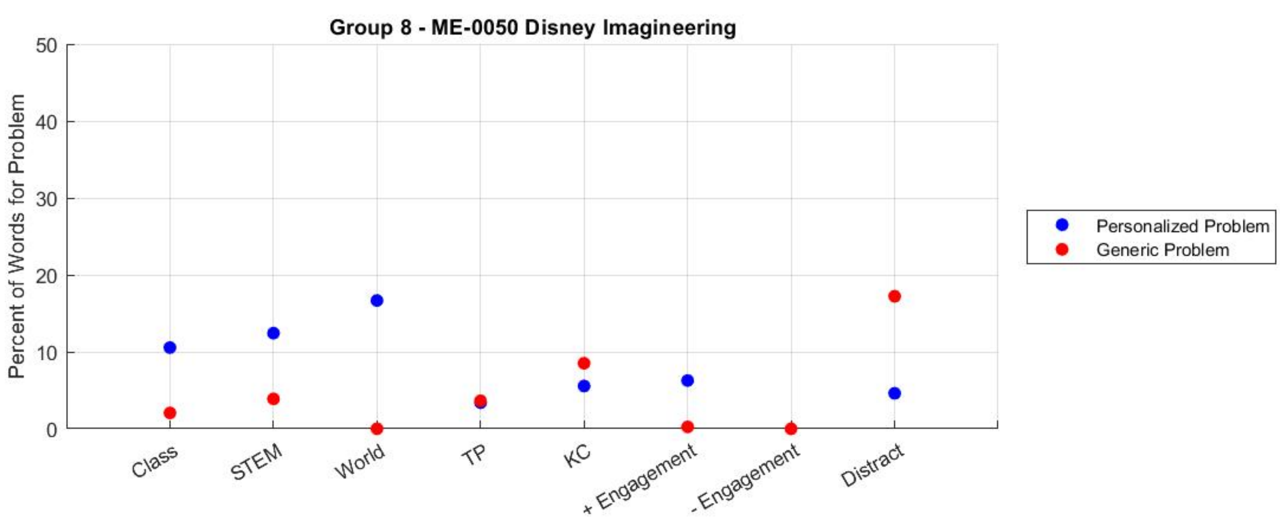

Group 3 - ME-0050 Biofuel Bus
Percent of Words for Problem
50
40
30
20
10
0
Class
STEM
World
TP
KC
+ Engagement
- Engagement
Distract
Personalized Problem
Generic Problem

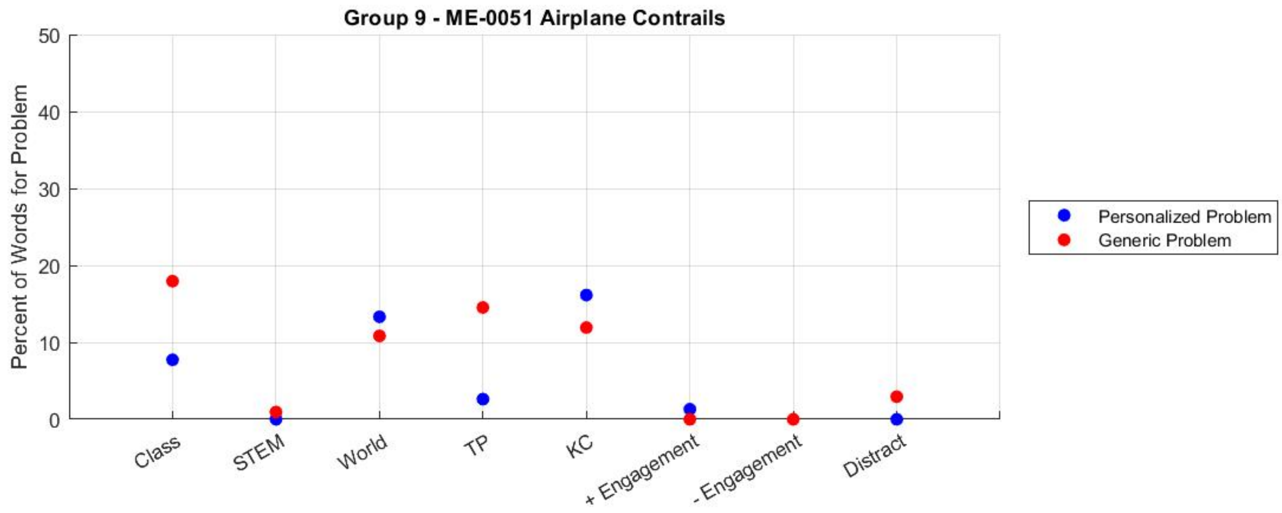

Group 4 - ME-0050 Disney Imagineering
Percent of Words for Problem
50
40
30
20
10
0
Class
STEM
World
TP
KC
+ Engagement
- Engagement
Distract
Personalized Problem
Generic Problem

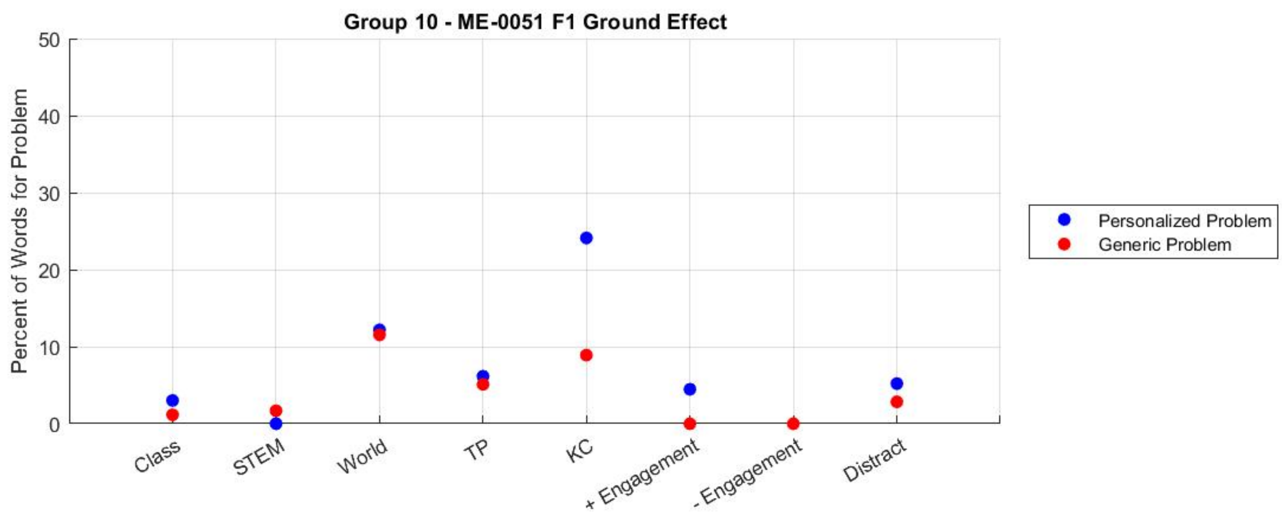

Group 5 - ME-0050 High-Altitude Plane
Percent of Words for Problem
50
40
30
20
10
0
Class
STEM
World
TP
KC
+ Engagement
- Engagement
Distract
Personalized Problem
Generic Problem

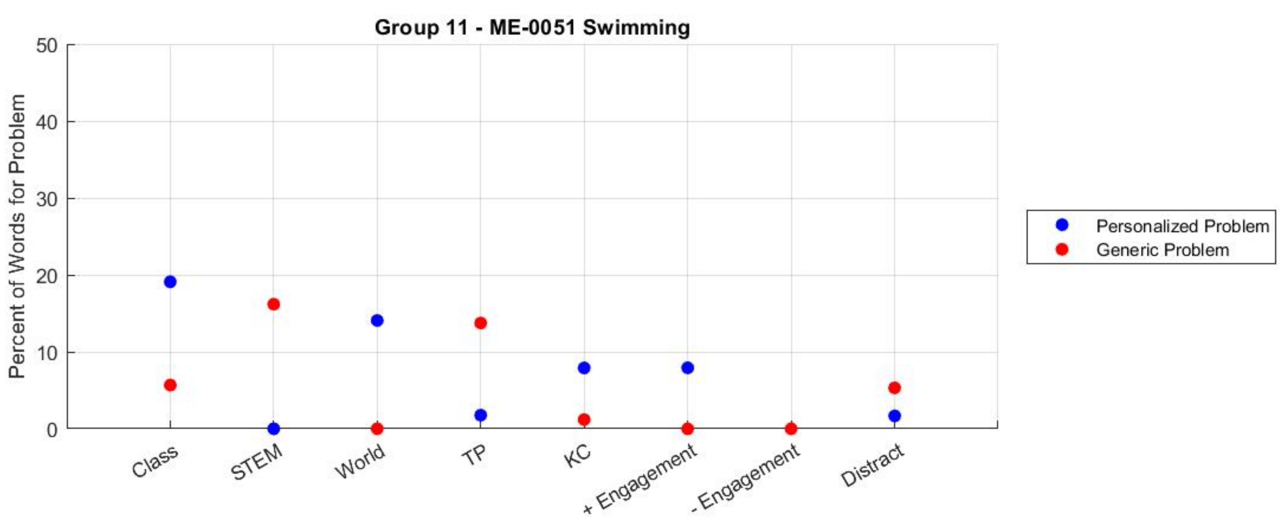

Group 6 - ME-0050 High-Altitude Plane
Percent of Words for Problem
0
10
20
30
40
50
Class
STEM
World
TP
KC
+ Engagement
- Engagement
Distract
Personalized Problem
Generic Problem


Group 7 - ME-0050 Rocket Fuel
Percent of Words for Problem
0
10
20
30
40
50
Class
STEM
World
TP
KC
+ Engagement
- Engagement
Distract
Personalized Problem
Generic Problem


Group 8 - ME-0050 Disney Imagineering
Percent of Words for Problem
0
10
20
30
40
50
Class
STEM
World
TP
KC
+ Engagement
- Engagement
Distract
Personalized Problem
Generic Problem


Group 9 - ME-0051 Airplane Contrails
Percent of Words for Problem
50
40
30
20
10
0
Class
STEM
World
TP
KC
+ Engagement
- Engagement
Distract
Personalized Problem
Generic Problem


Group 10 - ME-0051 F1 Ground Effect
Percent of Words for Problem
50
40
30
20
10
0
Class
STEM
World
TP
KC
+ Engagement
- Engagement
Distract
Personalized Problem
Generic Problem


Group 11 - ME-0051 Swimming
Percent of Words for Problem
50
40
30
20
10
0
Class
STEM
World
TP
KC
+ Engagement
- Engagement
Distract
Personalized Problem
Generic Problem

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