The Future of Engineering Education
2024 Annual Conference & Exposition
Oregon Convention Center
Portland, OR . June 23 - 26, 2024
ASEE
Paper ID #42909

Homework Problems as Epistemic Agents: Unpacking Students' Problem-Solving Approaches in a Technical Engineering Class

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Abstract:
Although lecture-based courses are common for teaching technical material to undergraduate engineering majors, it is well documented that they are not the best way for students to learn. However, significant barriers to change prevent many lecturers from transitioning towards research-based educational practices. A closer look at how students interact with and learn from homework problems — seen as a major influence of learning methodology to students — may help circumvent this tension by uncovering opportunities for accessible changes. In this paper, I qualitatively examine student problem solving paths through a situative lens: exploring the tension of agency between students, homework problems, and class norms, and characterizing under-researched strategies associated with learning in a technical class. Furthermore, I focus on how and when students use problems as epistemic agents.

Seven students who were enrolled in a thermal-fluids class at a university in the northeast US were each asked to solve two problems in a think-aloud interview. Thematic analysis of video recordings and student work products was conducted. In addition to student approaches that align with existing literature, I observed instances of students interacting with homework problems as though they were epistemic agents. Viewed through the cultural pulls of technical classes and the allocation of agency in both learning and problem solving, this finding can both help educators understand their students' approaches and serve as a warning for the implications of current teaching methods.

Introduction:
In a traditional technical engineering class, there are lectures where content is delivered, recitations where material is reviewed in small groups, and problem sets where students cement their knowledge of course material by solving homework problems. It is well known that lecture-based courses are not the best way for students to learn [1]. However, most instructors still teach this way [2], many assuming that motivated students will master content as they solve homework problems, regardless of delivery method. Students largely agree, most frequently citing assignments and assessments — such as homework problems — as influencers of their learning methodology [3].

Well-defined, constrained, single-correct-answer homework problems are standard in traditional technical engineering courses [4]. These problems are straightforward, easy to grade, and may draw inspiration from real engineering situations, but lead to "inauthentic" learning, where students learn techniques that allow them to get good grades without understanding material in a way that would be useful in the context of their field [5]. While other types of homework problems like open-ended or concept questions are occasionally used, there are barriers to their adoption. Instructors face time limitations derived from organizational and cultural norms and misconceptions about learning [6], [7]. Students find themselves uncomfortable with new problem types, often pushing back and/or struggling to transition partially through their educational career [8].

So instructors are inclined to provide students with well-defined homework problems. Unsurprisingly, tensions with these problems have arisen. One is the tension between providing students with a pre-prescribed solution path and having them create their own. Because there is often only one way to solve each problem, it may be tempting to provide steps for each problem type covered in class. Additionally, the recommended practice of scaffolding, starting with full problem-solving direction and then slowly removing guidance, suggests that providing students with step-by-step example problems will help them learn [9]. However, students who create their own problem solving methodologies perform better on exams than those who use pre-prescribed approaches [10], [11]. To learn best, according to work on productive failure and productive struggle, students take part in productive struggle where they are forced to thoughtfully engage with the material [11], [12], [13]. Manufacturing productive struggle for a large class of diverse students — finding the balance between problems so straightforward that students can quickly complete them and ones so complex that students get frustrated and give up — is challenging. In a large university setting under the constraints described above, it is impossible. In addition to problem complexity, there is the broader difficulty of attending to the cultural practices of schooling as described in the following section.

Theoretical Framework: Situativity and Agency

Students approach homework problems from the context of their school environment. They know the cultural cues and context specific techniques that direct them towards getting the right answer and scoring well in the class [4], [5], [14]. Because they are lectured to by a trusted authority figure, students come to rely on an authority-based epistemology [15], heavy use of course equations, and prescribed rules to solve problems [16]. As students develop their problem solving methodology using these problems, what they learn becomes intertwined with the situation of the learning: the classroom environment [14], [17], [18]. Correspondingly, when a student solves a course problem, it is a joint venture between themselves and the culture of the class.

Problem solving agency can therefore appear distributed. In philosophy, an agent is an entity with the capacity to act [19]. Agents have agency when they intentionally exercise this capacity [19], [20]. When an agent is “capable of taking [intentional] epistemic stances towards epistemic elements,” able to exercise a capacity with regards to knowledge or knowledge creation, they are an epistemic agent [20]. One may assume that when a student solves a problem, they are acting as an individual epistemic agent and have full agency over the problem solving process. However, when understood in the context of an environment, a student might not choose (or even be unable) to exercise capacity as an individual agent [18], [21], [22]. Students exist in the world of the classroom [18], [22], build emerging engineering identity [23], and bring their prior lives and understandings with them into the problem solving process. As each of these facets fluctuates in a student's mind, epistemic agency may appear to move between several sources.

Something does not have to *be* an epistemic agent to be treated as if it were one. In the late 1980s, Daniel Dennett described the intentional stance: when a person interprets an inanimate object as having wants and beliefs [24]. Through the intentional stance, students can treat problems as epistemic agents in the problem solving process. But why might they do this? In the culture of the classroom, students are taught to trust their professors as the ultimate authority on subject matter [15]. Homework problems come from these professors. They wrote them, or at the very least, thought they were good enough to give. In assigning them, they engage in implicit agreements within the class context including

- The problem has a single, correct solution
- The problem is solvable with the material covered in class
- All of the information (numbers, variables, assumptions, etc) are in the problem
- Solving these problems will help students get a good grade on the exam
- Getting good grades on the exams means a student will be a good engineer

It does not matter if these things are true everywhere, they are true within the culture of academic life [18]. In this context, the problem is an extension of the hierarchy of learning. Since it is a component of the system that helps them learn, students may treat it as an epistemic agent.

Research Questions

Through this study, I seek to describe the problem solving approaches students deploy to solve well-defined, single solution homework problems like those found in many of their technical engineering courses. The research questions are as follows:

- Can interpreting student problem-solving paths through the lenses of situativity and agency grow our understanding of student-problem interaction?
- Where — if anywhere — in the problem-solving process do students attribute agency to written homework problems?

Methodology:

Research Design:

This qualitative research study utilizes thematic analysis of video recordings to examine seven think-aloud problem solving interviews. IRB approval was granted through the participating university and all students provided informed consent.

Participants:

This research was conducted at a private university in the northeastern United States. All participants were undergraduates enrolled in the same thermal-fluids course, a required course for both mechanical and nuclear engineers. Recruitment was conducted on the course Canvas page. A summary of the study, a consent form, and a Calendly link to sign up for a time slot were all included in the recruitment post. A reminder email was sent the day before their time slot. The demographic breakdown of participants is as follows:

- 3 self-identified as male, 4 self-identified as female
- 3 self-identified as a cultural or ethnic minority, 1 self identified as not a cultural or ethnic minority, 3 did not disclose
- 1 self-identified as second-year, 4 self-identified as third-year, 2 self-identified as fourth-year

Data Collection:
All data was collected over the course of three consecutive days, approximately two weeks after the first of three course exams. After the informed consent process, each student was given two unfamiliar problems: a thermodynamics problem involving a refrigerator and some bottles and a fluids problem involving ice in water. The order of the problems was randomized. Both problems were based on old exam questions that students did not have access to. The Thermodynamics problem was based on material from the first exam. The Fluids question was based on material that had been covered in class and at least one homework assignment, but not yet assessed in an exam. The timeframe of the study was deemed appropriate because it ensured that students had time to receive and look through their first exam without being too distant from the material. It also allowed them adequate time to focus on the next unit and avoided common testing periods where students may be too occupied with coursework to volunteer for the study.

Data Analysis:
A summary of the data analysis method is shown below in Figure 1:

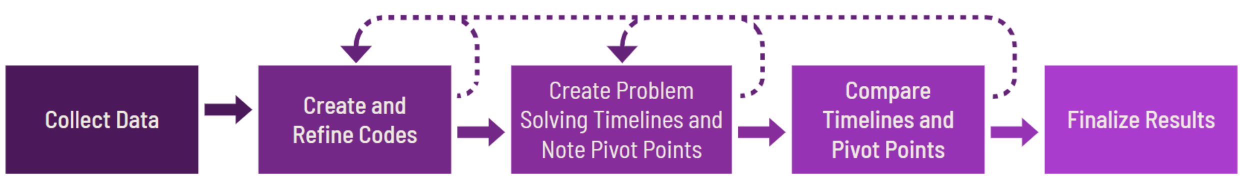

Figure 1: Data Analysis Flow Chart

Emergent coding was utilized to classify students' approach and process. This process was done iteratively, as codes were identified and refined. The codes were then organized into timelines of problem-solving steps and pivotal moments for each student. Student timelines were compared and major areas of similarity and difference were noted. Throughout this process, I revised the codes to more accurately capture problem-solving trajectories.

Results and Discussion:
Two major findings are outlined in the sections below. The first finding focuses on two distinct problem solving approaches seen in the fluids problem, and how these approaches can be seen through the lenses of agency and situativity. The second finding is a detailed exploration of a

student engaging in direct dialog with the problem. In this instance, she uses the problem as an epistemic agent that tells her what the 'right' and 'wrong' approaches are.

Finding 1: 'Illogical' Problem Solving Paths

Results:

For each of the two problems, there were several similarities in student problem-solving paths. One commonality of note was the high-level path most students took to solve the fluids problem. In the fluids problem, students were asked to determine if the water level in a cup will increase, decrease, or stay the same as an ice cube melts. It would be expected that a real-world problem-solver would start by identifying the root problem: how does the volume of liquid after melting compare to the volume of water displaced by the frozen ice cube? They may write expressions to compare the initial and final states. Given the information provided in the problem, they would see that there is a gap that can only be filled by an equation relating the density of ice and the density of water. Knowing that an equilibrium equation could fill that gap, the problem-solver may then draw a free body diagram to help them create that equation, and eventually finalize their answer.

While one student took this approach (and succeeded in correctly answering the problem), the other six did not. Although there were some differences in the details of their approach, the other students all flipped two major steps. Instead of starting by thinking about volumes, these students began with a free body diagram and/or equilibrium equation. When this approach did not find them a solution, they attempted other approaches, settling on an argument relating pre- and post-melting states. These two approaches, which we will call the logical approach and the school context approach are described in Figure 2 below:

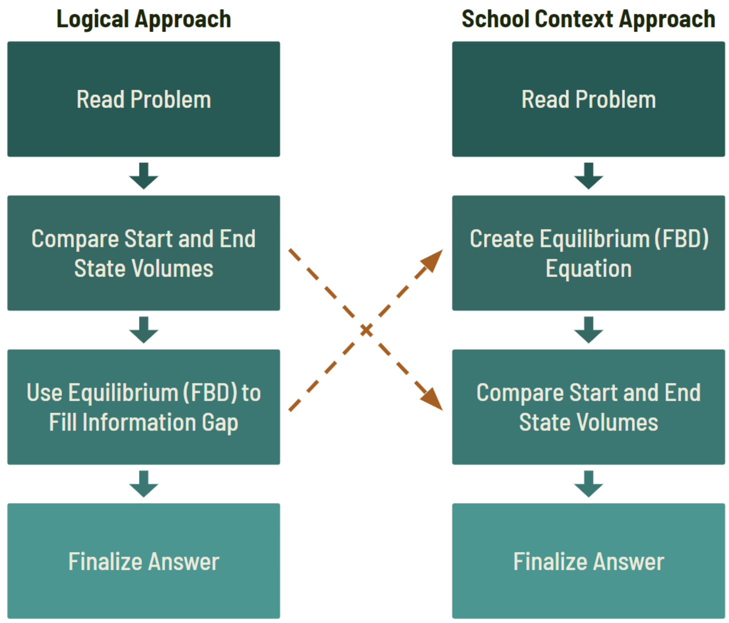

Figure 2: Approach Comparison Chart

After reading the problem, the school context approach students confidently began their free body diagrams, as if they had done it a million times before. They compared the two forces on the ice cube: the buoyant force and the gravitational force. They wrote down an expression equating these forces and began to simplify it. Then, they… stopped. What they wrote did not tell them if the water level changed. They were, at least temporarily, stuck.

A couple of the students moved on quickly. Many took time to ponder. Most expressed some sort of confusion. They said things to this effect. One pointed to the free body diagram and said,

> *2.30.430* *I guess all this is unnecessary.*

Another

> *14:09.690* *I don't think there was any point in me doing that.*

Yet another took a long moment of silence then eventually noted,

> *8:55.890* *I feel like I'm not getting it like anywhere with like trying to justify it with a free body diagram*

She had guessed the final water level would be the same when she first read the problem.

Other students were concerned that the free body diagram didn't get them anything new declaring,

> *7:55.350* *That just like gets back to the equation that we already knew*

or ,

> *14:.44.860* *I don't think that's really strictly necessary, just because the end equation is just a bunch of known variables.*
>
> *14:54.870* *So I don't think that helps me very much.*

In addition to what they said, many of the students had a physical reaction to their discovery. When they were initially working, they did it as if on autopilot: all the steps looked familiar. They moved with an even pace of progress and no expectation of difficulty. When they got stuck, several students looked like they had come out of a trance: like they had walked into a room and immediately forgotten why. There was slight disappointment or confusion in several of their reactions, but most shook it off as a peculiarity and tried to move on to a different approach.

One student was successful in this endeavor, able to compare volumes before pulling the equilibrium information back into a solution. However, the other five were not, even though they eventually attempted a volume comparison. It appeared difficult for students to use the information from their initial, ‘failed’, attempt to help with their final solution. This is articulated particularly well by one student. After she tried the free body diagram approach and the volume approach, she finished the problem by concluding that she was not able to determine if the water level increased, decreased, or stayed the same. She described her difficulty,

20:08.880 *just by comparing if you know whether or not*
20:12.840 *rho_i over rho*
20:15.810 *water times L is greater than*
20:22.260 *h, then it displaces. Then the water level rises. But I think it's just dependent on*
20:30.260 *the values of rho_ice and rho_water because I don't think you can.*
20:35.680 *Doesn't seem like you'd be able to solve specifically whether or not increases or decreases unless you have*
20:45.930 *the relationship between the densities. Probably is a way. But I don't know.*

But part of her did know. When attempting to solve with a free body diagram, she had derived an equation that describes the relationship between the densities. It was written in the middle of her paper, only a few inches from where she concluded. Figure 3 shows her work.

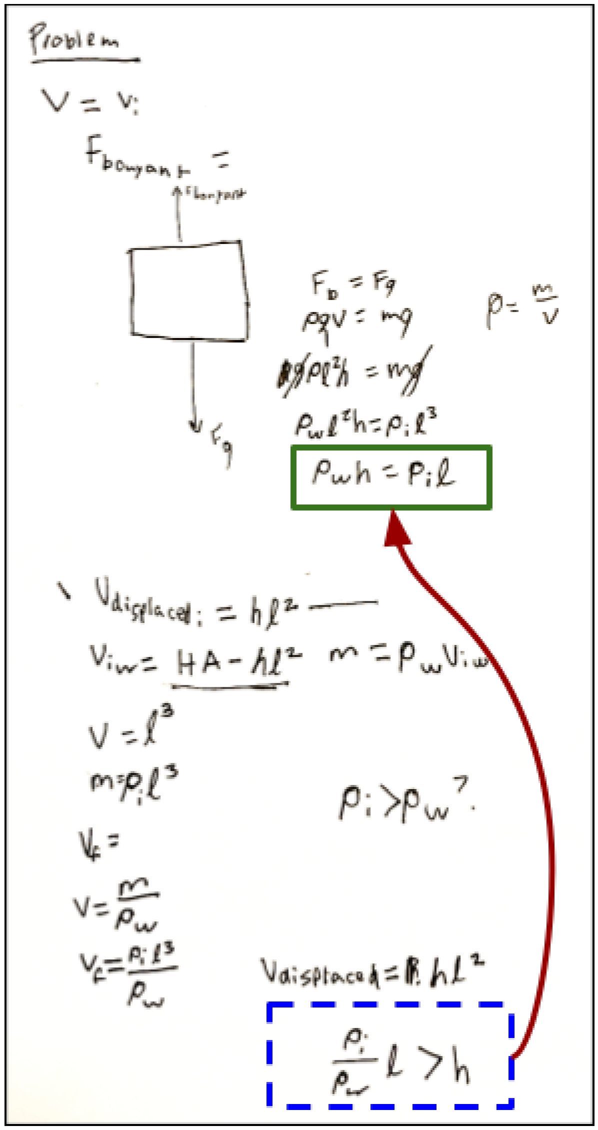

Figure 3: Student handwritten notes, adapted with boxes and arrows

In the blue, dashed box is the comparison the student is referring to when she says, “if you know whether or not rho_i over rho_water times L is greater than h, then it displaces. Then the water level rises.” At this moment, she does not know if the inequality she has written is correct or not, but she knows it is part of the way to her answer. She continues, “But I think it's just dependent on the values of rho_ice and rho_water because I don't think you can. **Doesn't seem like you'd be able to solve specifically whether or not increases or decreases unless you have the relationship between the densities.** Probably is a way. But I don't know.” At the other end of the arrow, in the solid green box is the relationship she knows she needs. Even though she already derived it, she states that she doesn't know how to get it. This example illustrates the disconnect several students faced between the steps they had taken, and their ability to identify it as useful work.

Discussion:

The school context approach to problem solving, pivot point confusion, and disconnect in student thinking can all be understood as part of the same phenomenon when seen through the lenses of situativity and agency. As discussed in *Background Information,* students are part of the culture of the classroom. In this culture, knowledge comes from sources of authority. Single solution homework problems come from these sources and exist within the culture of the class. After attending a few lectures seeing several example problems, students know that free body diagrams go with fluid statics problems. In this way, the problem (and problem type) becomes an extension of the authority of the instructor. Just as an instructor tells the students about theory and equations, the problem tells the students how to solve itself; the problem becomes an agent in the problem solving process.

When students embedded in school culture see a homework-style problem, they cede their agency to the class structure and immediately start solving the problem as they imagine an instructor would advise. After years of reinforcing this strategy, they *know* that this is what they *should* be doing. It's gotten them this far.

As they began writing, most study participants were likely not thinking about the root question of the problem or the utility of the methodology they were deploying. They were on autopilot: giving their agency to the problem, and correspondingly the greater learning culture this style assignment represents. But when the prescribed solution did not get them an answer, they needed to do something else. For some students, this may lead to a moment of productive struggle and knowledge building. For others, it can lead to more confusion. As described above, snapping out of their familiar workflow appeared to be a strange moment for most participants. Even though most brushed it off a mere inconvenience, they struggled to connect their work before and after this moment. One explanation for this may be as follows. A student creates the false logic: ***if*** *one method did not get me the answer,* ***then*** *it was not helpful.* For the fluids problem, this leads to the conclusion that work related to their free body diagram/equilibrium equation was not helpful.

Once the students have taken back some agency as problem-solvers, they begin to make progress. But they need more information to solve the problem. Even if they know what they are looking for and what they are looking for is written on the page, they may not be able to find it. Because students did not engage in the reasoning that directed them to an equilibrium statement, they may be unable to recognize its future utility. Additionally, their situation has changed. The equilibrium method was rooted in school norms and culture. After it failed, the students were left to find a solution on their own. In getting stuck, they shifted contexts and found it difficult to return.

Finding 2: Problem as an Epistemic Agents in the Thermodynamics Problem

Results

Like in the fluids problem, several students began the thermodynamics problem with heavy reliance on pre-prescribed problem solving steps and without an expressed understanding of how they were going to gather all of the information they needed. In the thermodynamics problem, students were asked to calculate the work needed for a fridge to cool bottles down to a certain temperature. If a student stuck with the classroom approach of determining a system and correctly using the first and second laws of thermodynamics, they could solve this problem. However, the students still had to make several decisions to set up their problem. To do this, some students looked towards the problem itself. In one illustrative example, a student decided her system by engaging in dialogue with the problem. She narrated,

21:07.340	*Ummmmm. Oh.*
21.14.120	*oh, system - the system!*
21.19.640	*What should be my system?*
21:27.950	*The system should be*
21.34.690	*I'm gonna say the system is like the air inside the refrigerator.*
21.41.390	*And then.*
21.45.070	*okay, this question is basically asking*
21.47.870	*what it takes to cool the air to 5 degrees. Since we're assuming that the temperature is equal to the bottles, so we can just ignore the bottles*
21.56.500	*right? Oh, but it gives the mass of the bottles which feels like I can't ignore the bottles. They also give the specific heat so I definitely can't ignore the bottles.*
22.11.750	*But the temperature inside the refrigerator is equal to the temperature of the bottles.*
22.17.520	*and it doesn't.*
22.23.040	*It actually doesn't give the specific heat of*
22.29.850	*the air inside the refrigerator. So I should ignore the air and use the bottles as my system.*

In this interaction, the student starts with an idea of what the system should be based on her understanding of the real-world situation the problem is trying to represent. When she says, “this question is basically asking what it takes to cool the air to 5 degrees,” she is restating to try to find the root question. However, she doubts herself when she sees the details presented in the problem. First, she notices the mass of the bottles. This alerts her that it may not be right to neglect the bottles. Then, she realizes that the problem gives the specific heat of the bottles, but not the air. This confirms her suspicions. In the end, she changes her system to match what the problem is suggesting, without going back and adjusting her understanding of the physical system.

The specific wording she uses during this transition is also significant. The student talks about what she “can’t” do or what she “should” do in reference to information the problem provides. The problem itself is referred to as both “it” and “they”, demonstrating the fuzziness of the boundary between problem and creator(s).

Discussion
In this moment, the student is using the intentional stance to view the problem as an epistemic agent in the problem solving process. There is full dialogue and shared agency between the two interlocutors. One represents the student; she is attempting to engage with the problem, maintaining suspension of disbelief that the situation written on the page in front of her is real and she is going to use course material to learn more about it. The other represents the class; someone wrote this problem with the intention of it being solved by students like her. Of course, the problem is not real. It is a story that exists only on paper. The student and the paper talk, and the suspension of disbelief collapses. The written problem, with the full force of school culture behind it, dictates what she can and can't do to get the right solution.

Limitations:
One limitation of this study is the small sample size: seven students, each completing two problems. These students are all from the same university and enrolled in the same class. Therefore, the results may not be generalized to different student groups. Additionally, these are students who self-selected by responding to the recruitment announcement. Although the students are diverse in gender, minority status, and exam performance, there may be self-selection bias in the sample.

Implications for Educators and Future Work:
It is my goal that this paper help educators empathize with and better understand the thinking of their students. Additionally, it can provide context for seemingly nonsensical student methods that frustrate educators.

This paper is also an addition to the chorus of voices implying deep issues with the current educational system [1]. If the problem, the representative of the culture of school, plays such a large role in student problem solving approaches, then how will students solve real life engineering problems outside of this context? Many researchers have studied students’ ability to solve real-world problems with bleak conclusions [5], [25], [26]. Additionally, there has been significant and inspiring work to understand how students may learn better from open-ended problems [27], [28] and project-based courses [29], but significant barriers prevent their widespread adoption [6], [7], [16], [28]. There has been little research that digs into the peculiarities of the status quo and even less that suggests a direction for piecemeal progress. Describing student behavior and contextualizing practices that might otherwise be chalked up to misconceptions or carelessness can serve as a foundation for future research into the adaptation of homework problems for enhanced learning outcomes.

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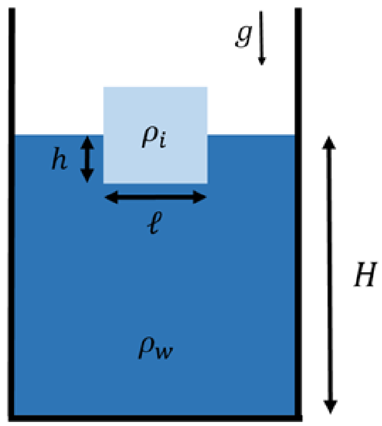
Appendices:
Example problems:

Ice and Water

A cube of ice with side length l is floating in a cup filled with water. The submerged height of the ice is h. When the ice melts, does the height of the water H increase, decrease, or stay the same? Please develop expressions to justify your answer. The density of the ice and water are ρ_i and ρ_w, respectively.



Cool drinks on the beach

It's the week of Spring Break; after months of relentless snowstorms in Boston and considerable suffering in classes, you and your buddies are enjoying a few days of well-deserved R&R on the Florida coast. You brought six bottles of an age-appropriate drink to the beach, but forgot to put them in the refrigerator and you don't have a cooler. The bottles are now at ambient temperature (T_{amb}=35°C or 308 K): you can either have your drink warm (in which case you will receive zero credit on this problem) or use your newly-acquired knowledge of thermodynamics to determine what it would take to cool the bottles. There is a small refrigerator at the tiki bar; you put the bottles in the refrigerator and plug it in a power outlet. The bottles (including their liquid content) have a total mass of 3.1 kg and an average specific heat of 2900 J/kg-K.

a) Taking the refrigerator (but not the bottles within) as the system, draw a 'black-box' schematic diagram showing all the energy transfers (including their sign) between the system and the environment.

b) Calculate the work transfer required by the refrigerator to cool the bottles to 5°C (278 K). In doing so, you may assume that the refrigerator has a COP which is only 70% the COP of a reversible refrigerator. You may also assume that the refrigerator itself is massless, therefore it does not store either energy or entropy. This implies that the temperature inside the refrigerator is equal to the temperature of the bottles at any given time during the process.