

**AC 2007-750: DEVELOPMENT OF AN ONLINE TEXTBOOK AND RESEARCH  
TOOL FOR FRESHMAN ENGINEERING DESIGN**

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# Development of an Online Textbook and Research Tool for Freshman Engineering Design

## Abstract

In many engineering design texts, the solution(s) to design problems are provided along with the proposed problem. Therefore, the student will read about the solution rather than take the time to think about the problem being presented. This paper explores the development of and pilot study done on an online textbook and research tool, based on the book, "How to Model It," by Starfield, Smith and Bleloch.<sup>1</sup> With this online system, students are able to read only a portion of the text, and then must complete one or more tasks related to the modeling problem, then submit a response to the system. Their responses are captured and available for their review (but cannot be changed). Once their response is submitted, they can then proceed to read subsequent text where they might, for example, compare their responses with 'expert' design methods for that problem. Through this approach, students are forced to begin practicing the engineering design process, rather than simply reading about someone else's solution to the problem. This format allows engineering design instructors to look at the effectiveness of their teaching methods on student design learning in such areas as heuristics, problem definition, etc. Besides allowing instructors to assess their students' design learning process, the 'online book' generates data of potential interest for research on design learning. For research purposes, videotapes of the input process have been used to determine the amount of information, if any, lost during the participants' solving of the design problem on the computer (i.e., discussion of ideas not presented in the input response). The video data has shown that most ideas, heuristics, methods, etc. discussed by the students during the exercise are included in the data input as responses into the system, making this a useful tool to research student learning. Currently, the data produced using the online text is being compared to the same problems completed using more traditional methods (i.e., paper and pencil, followed by a computer report). We expect to find little difference in the data provided by these methods.

## Introduction

Design process learning is a field of much recent interest in the engineering education community. Many approaches have been used to examine the ways people use the engineering design process. One of these methods, verbal protocol analysis<sup>2</sup> produces very detailed information on a student's design process thinking through the 'talking-out-loud' method. This type of analysis is extremely time-consuming, which severely restricts the number of subjects that can be included in any sample. Another method, analysis of student design journals, has also been used for analysis of the design process,<sup>3</sup> but unless regularly monitored for content, journals may not provide detailed information about the students' day-to-day design learning. Both of these approaches look at vital aspects of engineering design learning, but due to the time considerations for data processing and the desire to have continuous monitoring of students' design learning, neither of these methods allow for frequent glimpses at student learning over the course of a semester.

In addition to our research interests in engineering design learning, we are also interested in the pedagogy of engineering instruction. In many engineering design texts, the solution(s) to design

problems are provided in the pages following the proposed problem. Therefore, it is our experience that students will nearly always read ahead to the presented solution (if one is available) rather than take the time to think about and generate their own solutions for the problem being presented in the text. Reading about a process does not necessarily promote student learning of problem solving strategies; in contrast, active engagement with the material will more likely provide students with a deep understanding of the concepts discussed in the text.<sup>4</sup>

The purpose of this study was two-fold: to develop an online textbook to enhance engineering students' learning in their first design course, and to use the information gathered from this online text to investigate student learning of the engineering design process during this course. Therefore, a program has been developed based on the engineering design textbook, "How to Model It," ("HTMI") by A.M. Starfield, K.A. Smith, and A.L. Bleloch,<sup>1</sup> that permits both of these goals to be realized.

## **Methodology**

As previously stated, in many engineering design texts, the solution(s) to design problems are provided in the pages following the proposed problem, allowing the student to read ahead to the 'expert' solution to the problem directly after the problem presentation. In order to prevent such reading ahead, we have structured an online text delivery approach that presents the HTMI text in short chunks, each of which are followed by interactive portions containing questions and design problems (essentially as presented in HTMI). The interactive questions or design problems posed are directly related to the content preceding them, and students are required to submit an answer to each interactive section before continuing in the text. The difference from the standard physical text then begins. First, their responses are captured and available for their review (but cannot be changed). Secondly, they cannot proceed to read subsequent text where they might, for example, compare their responses with 'expert' design methods for that problem, until AFTER submitting their own response. Through this approach, students are forced to interact actively with the text content; in this case to begin practicing the engineering design process, rather than simply reading about someone else's process and closely copying the example. Students are also involved with metacognitive processing of the material, as the questions they are asked are rarely if ever 'single-right-answer' questions; rather, they are asked to discuss and compare the 'expert' solutions to their own, and explicitly asked to iterate what they have learned through the process of reading and completing each of the scaffolded design activities. Students are encouraged to be thoughtful in their responses as a portion of their grade is based on the completion of these entries.

For the alpha test of the online text, each interactive question or design problem was 'scaffolded,' having a small set of instructions to accompany it (see Appendix A for an example section of the chapter). The instructions included specific details for completion of the problem, such as tasks to complete, proper format for inclusions of drawings and/or equations, and reminders about describing their thought processes not just a final answer. For example, users were provided sheets on which to complete supporting work on a problem, they were instructed not to use scratch paper for testing out sketches or equations, but to use the sheets provided for that purpose. These instructions were designed to keep the students focused on their process,

and to help them recognize through practice that the road to the final answer can be as important as the answer itself. These instructions were also meant to give support to the research goals related to the online interactive text. Data from the alpha test was analyzed to determine whether students included design process thinking in their responses to the interactive questions (such as false paths taken prior to their final solution, steps they took to arrive at their solution). In addition, metacognitive thinking processes were also noted.

For the pilot study, the ‘scaffolding’ instructions that accompanied each of the questions were not included (see Appendix B for an example section of the chapter). Prior to the beginning of the assignment, students were instructed orally to include their process thinking and asked to turn in all drawings and hand-written notes and/or equations that they developed during the assignment. The change was made to determine if the ‘scaffolding’ included in the alpha test was necessary to achieve both the instructional and research goals for the text. The assignment was completed during one class period (one hour and 15 minutes) by student design teams in an introductory engineering course (Introduction to Chemical Engineering). Student groups were videotaped during the completion of the assignment. These videos were compared to the actual answers input for the interactive questions to determine the quality of the answers input with respect to the discussions the students had during the completion. In addition, both the videotape and student answers were analyzed to determine whether students included their design thinking in their answers to interactive questions.

## Results

### Alpha Test (Spring 2006)

For the alpha test, one chapter of the online HTMI text was used as an end-of-semester individual extra credit assignment in two sections of a freshman engineering design course. The data obtained from the interactive questions contained more information than was originally expected from such an assignment. The students were diligent in following the directions that accompanied each question, and provided many details about their design process thinking. Student responses included some false paths, later abandoned, along with their final solutions, supplying a rich description of their thinking about the problem. Furthermore, the answers provided by the students covered a wide range of ability levels, as would be expected in a freshman course with students of varied backgrounds. The amount of detail that students provided in their problem solving did show great promise for use as research data when the online interactive text is used over the course of an entire semester. A sample of one student response to the first interactive section (see Appendix A for the question) was:

“Add required treated water 2 minutes. Start agitator. Add preservatives, and mix until dissolved 30 minutes, Add nutritive sweetener 1 minute. Add flavor concentrate and color rinsing containers with water withheld for that purpose 5 minutes. Add carbon dioxide 2 minutes Add any remaining water to complete batch 1 minute. Agitate until completely mixed 40 minutes. Place into the bottle/cans 10 minutes; rinse all containers to remove all traces of ingredients 29 minutes. With the current algorithm, it takes approximately 2 hours (120 minutes) to make one batch. Therefore, 100 batches would take 200 hours. However if the

algorithm was changed, it may take less time to make a batch. But changing the recipe may produce undesirable results in appearance and/or flavor. There are questions that need to be answered before any change takes place. For example, is it required that the preservatives be completely dissolved before adding the nutritive sweetener? And more generally, what steps can be combined without adverse effects.”

As can be seen by this response, the student spent some time thinking about what might be changed to decrease the time for the process. Though the answer was not “optimal” (the expert answer was more time-efficient), the student was careful with detail of his/her modeling process and included details of the design process and questions s/he had about it. Since the focus of the text is to encourage design process thinking, not to find a “right” answer, that goal was accomplished in the alpha test. Most students spent time explaining their design process for each section and “rethinking” that process in the later sections after reading the “expert” solutions.

Though this study captured design process thinking from only a single problem, it showed that the students learned new skills from the online interactive text, even though they had both been instructed in these skills in class and produced an assignment covering the same basic material. When asked to reflect on their learning, each participating student stated at least one aspect of the process that they had not been explicitly aware of prior to the completion of this chapter of the online interactive text. Since this chapter dealt with making decisions on a ‘timed process’, it required the use of charts (such as a Gantt chart) or graphs (for example, a bar graph) to look at the process with respect to time. The students had spent time on these methods, both in a classroom lecture and as part of their final project; however, they did learn things from this chapter that they had not previously considered. Some student comments on their learning included:

“Throughout this whole chapter I have learned many valuable lessons. Firstly I have learned as to how we approach a specific problem. This chapter has taught me all the key concepts we need to keep in or mind while solving a problem. This chapter also enabled me to draw specific representations of a given problem to aid me in the problem solving process ... Hence, this chapter has made problem solving for me easier and much more systematic.”

“It has been interesting to see all of the factors that need to be taken into consideration. I have learned about separating tasks into dependent and independent paths to complete a particular process.”

“. I liked the strong points of interdependence and how the ideas of concurrence and precedence were presented. I also liked the way the chapter suggested moving the nodes on the timeline and writing a computer program to help with more complicated models.”

These students had completed their first course in engineering design (Introduction to Engineering, a ‘freshman’ course), but still found the creation of charts/graphs to solve an engineering process problem a challenge. The systematic thinking required for this type of

engineering problem was one of the main learning topics commented on by the students. By introducing the material in small chunks, the students had the opportunity to participate in the process before reading an “expert” opinion on the correct method. They learned about all the things that needed to be taken into consideration in order to complete the task given to them by comparing their solutions in each step to those presented in the text, making alterations to their own work, and reflecting on their process in light of each new chunk of information presented. In addition, many students also commented on the number of factors that needed to be considered to develop an optimal solution. By working through the problem at the same time as reading about the “expert” procedure, they really saw the factors that they were missing when considering their own solution. The text proved to be a useful learning tool for the students despite having covered the material to some degree previously in their class.

### Pilot Study (Fall 2006)

As a result of the alpha study’s success at achieving the intended goals, one chapter of the text was used for classroom exercise in Fall 2006. The exercise was completed by one section of the freshman course Introduction to Chemical Engineering, and by twelve class project teams consisting of 3-4 students each. This activity was not the first such interactive activity for the class, as it was given at the mid-point of the semester; and, the class was well versed in completing both computer-based and pen-and-paper activities on a regular basis. There was a time limit for completing the work of 1 hour 15 minutes. As future engineers, the students were learning about time constraints, as well as engineering design methods; therefore, their answers tended to be shorter than those provided during the alpha test, where students were given one week to complete the work.

Again, the groups’ answers to the interactive portion of the assignment provided good process information, comparable to the work done by the students in the alpha test. The students’ answers showed thoughtful, concise engineering modeling efforts considering their time limitations. It was determined from the responses of the students in the pilot test that the ‘scaffolding’ of questions was not necessary to obtain adequate process information from the text.

In addition, the comparison of the written work with the videotape of the completion of the assignment showed that there was little, if any loss of student response data using this system. The students’ written answers to the questions contained some ‘reorganization’ of the processes that were discussed within their groups (as observed on video) in order to put them in a more ‘readable’ format, but the outcomes were essentially the same. For instance, the answer to one question regarding assumptions for an air tank purging question was:

“Assumptions: Shape of tank, Location of valves: hot air input top right, cold air output left bottom. It has quantitative temperatures. We have five temperature measuring devices throughout the tank. One at input, output, and three inside.  
Plan: Create a flow control valve on input and output. Use the flow control valves to regulate input and output volume. We have reached our equilibrium when the output temperature is the same as the input temperature.”

The actual conversation corresponding to this computer entry went as follows: (Students in the group are numbered S1-S4)

S1	Reads question aloud.
S1	For assumptions we need to consider the shape of the tank and where the hot air is going in.
S2	Where the hot air is going in and cold air going out.
S3	Well the location of the holes.
S1	we're trying to pump hot air in.
S3	Hot air at the top and cold air at the bottom.
S1	Ok.
S3	That would work, that would mean the cold air would already be sitting at the bottom.
S1	There would be pressure for us to push it out.
S3	Yeah.
S1	Ok - so what are we shooting for the shape of it?
S4	A cylinder.
S2	Like a water tank or something.
S3	Shows a sketch (of cylinder with in/outputs, one at top, one at bottom).
s2	A potato?
S1	Whoa, dude - you know, um ...it was a .. Gas tank, right? Or what about the time?
S3	Lets just take as much as we need for this part
S1	Whatever's necessary.
s1	What about, um, you know the tanks they carry oil in on trains? Would that be a better assumption? The shape of the tank - that's more common for a gas tank
S2	So you're saying a hole on the top, a hole on the bottom.
S1	Yeah.
S2	So hot air in the top, cold air out the bottom.
S1	And it has the little dimple on the top.
S2	Lets make an algorithm up.
S4	Lets have assumptions for now.
S4	(Points at paper) she said that this is just for stuff that can't be done online.
S1	Well we can't draw that.
S1	Just write shape of tank.
S1	Where do we want the inputs and outputs of air.
S3	I'd say hot air at the top, cold air at the bottom
S3	(typing input to system)
S1	Ok - say, valves.
S4	Say location of valves.
S3	Hot air top right.
S1	Can we clarify that as an input and output.
S1	My 3-D drawing is ...
S2	That looks like a sub .
S1	So what other assumptions do we ...
S2	3000 meters cubed
S1	What about air pressure
S1	So what if we ... so what type of flow are we going to be getting into the tanks
S3	We should assume the temperature first.
S1	So it's generally cold and generally hot, so its going to qualitative not quantitative, so I don't think we need to worry about it, so make an assumption that it is qualitative

	temperatures.
S4	Is that an assumption?
S1	I think it's good to clarify
S2	That's a given though.
S3	It's stated anyways.
S1	Yeah.
S4	What else do we have to assume?
S1	So now, what about air pressures? Do we want to, um, have continual output of cold air as we input hot air?
S4	Would that be an assumption or would we be going into our plan right now? We have to come up with a flow chart.
S1	This would be a plan, we're going to make assumptions and then we're going back to the plan.
S2	How we're going to put in the air - that is more of a plan than an assumption.
S1	Do you want to move on to plan then?
S3	Yes.
S1	If we have any more assumptions we can go back then .
S2	So, basically, we're going to put hot air in at the top and cold air comes out the bottom.
S1	So do we want to have high flow hot air coming in the top, increasing the flow of cold air out the bottom?
S4	Maybe a smaller hole.
S1	That would be stupid..
S2	We don't want too big of a hole.
s1	So flow control valves on both input and output using
S3	(typing input to system)
S2	Create flow control input and output.
S2	Then after that we can just, basically say, pump hot air in and let the cold air go out, right?
S4	pump hot air in.
S1	It says that ... one more assumption that we need is that we need a way to measure the temperature .
S4	Oo-hoo, good call.
S1	at more than one place, because the temperature is not going to be the same throughout the entire structure.
S2	Why don't we just put 4 thermometers.
S1	So we have an output thermometer, an input thermometer, and, then in the middle?
S2	Yeah, sure.
S4	But won't the temperature be different in the tank?
S1	Yeah, so five thermometers.
S3	(typing input to system)
S1	Thermocouples - thermocouples linked to a computer.
S1	So for the plan, so to speak, we know we've achieved equilibrium when the output temperature is the same as the standard temperature in the middle, or the same as the input and we can stop the flow of hot air.
S4	Close the valves - that'll work.
S2	Yeah.
S4	So we're done now?
	(all read the computer input)



S1	We should probably include the flow control valves elsewhere in our plan.
S1	Use flow control valves to regulate input and output volume as we get close to equilibrium.
S4	What would it be pressure, speed?
S1	No volume
S2	Not pressure, because we have a valve open on the bottom and the top.
	(all read the computer input)
S3	Are we done?
S1	Let's make sure before we input it.
	(all read the computer input) - all appear to be thinking about it
S4	For assumptions don't we have to assume that the temperature is quantitative? Or else the thermometer would have no effect?
S3	I'll just say quantitative.
S4	Change it up 3 lines to quantitative.
S1	Good thinking.
S2	We good?
S3	Yeah, I'm good - you guys good?
S1	Yeah, we're good.
S3	Ok, submitted.

Comparison of the students' conversation and their online submission shows that the *assumptions* and *plan* that were made during the group's 14-minute conversation were all included in their submission. For the most part, the data that was lost included discussion over how to draw and word things, not the actual design work. However, the transcription of this short conversation on a single question took over two hours. Since one goal of this text is to provide a research tool that is less time consuming than 'talk aloud' methods, it has certainly proven to be so. A certain amount of data loss was expected; it was hoped that this loss of data would be offset by the time saved (this would enable us to look at many students' growth and learning processes over the course of a semester). We realized that the minute-to-minute data would not be included in the answers input into the system. However, as can be seen in this case, after comparing video-tapes to answers input, it does appear that essentially all relevant student design process data has been included in the student answers, such as assumptions, heuristics, etc.

As with the alpha-test, the students that completed the work in the pilot study supplied a rich description of their design process thinking about the problems presented. An example of a student team response to the first interactive question (see Appendix B) was:

"First, we defined the problem using the present state/desired state heuristic. See figure 1 on page one for this work. Next we formulated assumptions, that an equal amount of hot air would be needed to make the cold air warm. Next another equal amount (3000 m<sup>3</sup>) of hot air would be needed to make the temperature warmer (halfway between the temperature of the hot air and the temperature of the warm air). This process can be repeated until the temperature in the tank eventually comes close to that of the hot air. We are assuming the air in the tank doesn't escape much, but rather mixes with the incoming air."

As can be seen here, this team used a method previously introduced in the classroom (present state/desired state) to develop their design to “solve” the engineering problem presented. All of the teams used some heuristic that had been taught previously in the course to develop their initial designs (the second question asked for specifics about the heuristics they used) and drew on knowledge from previous courses, such as chemistry and physics, to develop a mathematical model of the process. Their answers to the questions were well thought out as a class, and provided the instructor with a good look at their ability to use the engineering design “tools” discussed previously in the course, making the text a good pedagogical tool as well.

The students were asked to comment on the usefulness of the chapter of the online text with respect to their final project, a hot-air balloon, which they had to design to meet specific design criteria. When asked about the usefulness of the chapter and the modeling they did, some student comments on their learning included:

“It got us thinking about physics and about certain factors like temperature and pressure that were very relevant to our balloon project.”

“It was really useful to promote the critical thinking associated with engineering problems. This model helped us implement the mathematics, chemistry and physics for the balloon project.”

“I referred numerous times to that specific problem to realign myself during the project.”

Many students commented on usefulness of learning to link chemistry and/or physics to the modeling process, an essential tool in the engineering design process. Not all of the students referred to this chapter during the completion of their project, but some did comment that they wished that they had remembered it during the rush to finish the modeling portion of the project, as they felt that it would have been quite useful. Overall, the students were quite positive about using the online text, both in ease of use and learning the modeling process. However, some felt that it would have been more useful to them had there not been the time constraints involved in doing the work in a classroom situation. The students did learn useful techniques, such as bringing in knowledge from other disciplines, during the completion of the problems presented in the chapter, reinforcing the text as a good pedagogical tool.

## **Conclusions and Future Work**

We have shown that data on student design learning generated through our ‘online text’ adaptation of HTMI shows a trade-off between the time saved and the minute-to-minute details when comparing transcription of students talking about their design process and writing about it. However, we judge that the ability to track many students over the course of a semester on a regular basis outweighs the relatively small data loss. The online method of gathering data about student design processes described in this paper will allow a different perspective to be gained on the student learning during their first semester of engineering design. The ability to sample students regularly throughout the semester will allow a deeper understanding about student misconceptions and growth than has been accomplished to date. We have also shown that

'scaffolding' for questions is not always necessary for getting high-quality data from the students using the text, so such detailed instructions will not be included with the questions in further development of the text. In addition, the online text should prove to be a useful pedagogical tool for introductory design courses. It will allow instructors to view the same processes as were just outlined for research.

As a pedagogical tool, the online text has proven to be a useful aide to student learning. The students benefited by working through problems, then comparing their solutions to the "expert" solutions provided in the online text. The students showed learning gains even though they had previously learned similar techniques, both in a traditional lecture and by using them for a class project. The process of working through a problem with "expert" help provided in the online text has proven useful in helping students learning sound engineering design thinking abilities and approaches to engineering problem solving.

Future studies will include looking at data loss with individuals, both in and outside of a classroom situation, with and without time constraints, using the same videotaping process as was used in the classroom. In addition, student work products will be used to look at student misconceptions about the engineering design process and student design learning processes. As a result of the alpha test, pilot study, and student input, future plans include adding an equation editor and a mouse drawing tool for sketches; there will also be continued module development, adding more online content each semester.

## **Bibliography**

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## **Appendix A. The Problem Statement and First Interactive Question for the Alpha Test of the Online Text Book**

### **The Problem**

The following was the problem statement (and first section of data) given to the students in the alpha test of the online textbook: It is a sample of the format presented to the students in the text. Data sections may include samples of graphs and charts, 'expert' solutions to previous interactive questions, modifications to criteria for the problem solutions, etc. The data section presented was:

Americans drink more water carbonated in soda than they drink plain from the tap. Globally, carbonated soft drinks are the third most-consumed beverage, and in 2000, Americans spent \$60 billion on carbonated soft drinks. The per-capita, annual consumption of carbonated soft drinks (7.7 gallons) is nearly four times the per-capita consumption of fruit beverages (2.1 gallons) as reported from the Beverage Marketing Corporation. Twenty-five years ago, teenagers drank almost twice as much milk as soda pop. Today they drink twice as much soda pop as milk.

Due to its high impact, we are going to analyze the process of making carbonated beverages. The ingredients needed are:

- treated water
- sweetener
- flavor
- color
- preservatives
- Carbon dioxide.

We want to estimate the shortest time in which it takes for 100 beverages to go from the ingredients to the bottle without leaving out any ingredients. The time to get the product into the packaging should be included.

### **THE DATA**

The following are your best estimates of the times needed to complete the various activities associated with the production of the carbonated beverage:

- Add required treated water, withholding a quantity sufficient to rinse all containers to remove all traces of ingredients – 2 minutes
- Start agitator. Add preservatives, and mix until dissolved – 30 minutes
- Add nutritive sweetener – 1 minute
- Add flavor concentrate and color rinsing containers with water withheld for that purpose – 5 minutes
- Add carbon dioxide – 2 minutes

- Add any remaining water to complete batch – 1 minute
- Agitate until completely mixed – 40 minutes
- Place into the bottle/cans – 10 minutes

Remember these are average approximations. To save some time you can add some ingredients while mixing them at the same time or add all the ingredients at the same time and then mix them all together, so it takes shorter time. Also, you can decide not to add color or add water only once, or even mix only once for longer time. There are various approaches to the problem to minimize the process time.

### **The Interactive Question**

The following is the interactive questions relating to the problem statement presented above (including the instructions given to the students about how to present their answers):

How quickly can you make 100 carbonated beverages?

*You should be able to get the answer in 15 to 20 minutes, but take a little longer to think about how you got there. How, for instance, would you persuade somebody that the answer you have found really is the shortest time?*

Instructions: In this section, put down all your thoughts on this process in the order that you try them. Put down equations and/or sketches and rough graphs on the paper you were provided with for that purpose. Please make sure that you included references (the numbers) for these equations, sketches and graphs in your notes. Please limit your time to 15-20 minutes.

## **Appendix B. The Problem Statement and First Interactive Question for the Pilot Study on the Online Text Book**

### **THE PROBLEM**

The following was the problem statement (and first section of data) given to the students in the pilot study on the online textbook: It is a sample of the format presented to the students in the text. Data sections may include samples of graphs and charts, 'expert' solutions to previous interactive questions, modifications to criteria for the problem solutions, etc. The data section presented was:

#### **PURGING A GAS STORAGE TANK**

A gas storage tank has a volume of  $3000 \text{ m}^3$ . It currently contains cold air. The tank must be replaced with the hot air. Hot air is available as much as needed and can be pumped into an opening near one end of the tank. Another opening (near the other end) will let gases escape. How much hot air will you need to dilute the cold air effectively?

### **The Interactive Question**

The following is the interactive questions relating to the problem statement presented above (including the instructions given to the students about how to present their answers):

Your first task is to develop an approach to this problem: in other words, a plan for determining how much of hot air will be needed.

*Take about 10-15 minutes to prepare your plan and to come up with a representation that helps to explain it to others. Your representation could be a diagram, a set of equations, a flowchart, an algorithm, or whatever format you choose.*

*If you find it difficult to develop a representation then make a list of questions you would like to ask, or assumptions you would like to make.*

*Do not actually try to solve the problem at this time. Also, remember that the decision to use hot air has already been taken; you may have thought of using water to purge the cold air or have had other bright ideas, but that is not the problem you have been asked to solve.*