

# Elements of a Cognitive Model of Physics Problem Solving: Epistemic Games

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## Auxiliary Appendix

### 1. Description of Course Reforms

This reforms that enabled this study were carried out as a part of the *Learning How to Learn Science: Physics for Bioscience Majors* carried out at the University of Maryland from 2000-2005.<sup>i</sup> The goal of this project was to determine whether an introductory physics course could serve as a venue to help biology students learn to see science as a coherent process and way of thinking, rather than as a collection of independent facts; and whether this goal could be achieved within the context of a traditional large-lecture class without a substantial increase in instructional resources. In addition, the project was structured so that much of the learning that would take place in the class would occur in locations that could be observed with our video cameras. This led us to collect a substantial amount of ethnographic data, both video recordings of problem solving, tutorial sessions, and laboratories, and student created artifacts – homework and examination papers.

The project adopted reforms that were well-documented to produce conceptual gains and adapted them to try to create a coherent package that produced epistemological and metacognitive gains. We hoped that this could be done without sacrificing the conceptual gains associated with these reforms and this indeed turned out to be the case.<sup>ii</sup> The specific reforms undertaken were as follows.

Homework problems: Problems were regularly assigned and graded. Due to limited availability of TA time, the grading was restricted to careful grading of one problem per week with written feedback, with the other problems being graded “lightly” – given a score of 0 or 1, with no feedback given. Carefully written homework solutions (including substantial discussion) were prepared and students were warned to look carefully at the solutions and not take for granted that a grade of “1” on a lightly graded problem meant that they understood it or even had it correct – only that they were mostly on the right track. (We have no data as to how many students took this admonition seriously.)

The problems assigned were not traditional end-of-chapter textbook exercises. Instead, they included a mix of challenging activities including representation translation problems, context-based reasoning problems, ranking tasks, estimation problems, and essay questions with epistemological content. (For more on these types of problems see chapter 4 of Redish’s *Teaching Physics*.<sup>iii</sup>)

The instructor (Redish) expected that each problem would take the students about an hour to complete, and he communicated this expectation to the class. In accordance with his expectation, the instructor only assigned about five problems each week. Because these problems were assigned as homework and graded, our observations of students working on these problems gave us an authentic look at how students actually behave in real-world classroom problem-solving situations – as opposed to watching them solve problems artificially posed to them in an interview environment.

Lecture: The lecture was given by the instructor in a large lecture hall to about 100-160 students. The class met three times a week for fifty minutes. Two modifications to the lectures significantly increased student attendance and participation.

(1) The *Peer Instruction* environment<sup>iv</sup> was adapted for this class. Each student was issued a *remote answering device*. The instructor periodically asked a multiple-choice question during the lecture to which the students responded using these devices. A computer automatically displayed a histogram of the results. This reform was modified to focus on epistemological issues. Discussion before the question often focused on students' intuitions based on their real-world experience. Discussion after the question often focused on the wrong answers, why they were chosen, and whether even they had a "correct" intuitive core. The goal was to encourage students to not just "know" the right answers, but to perceive them as both plausible and intuitive.

(2) The *Interactive Lecture Demonstration* (ILD) environment<sup>v</sup> was adapted for this class. About a half-dozen times per semester, students received a worksheet outlining specific questions that were to be discussed. The instructor led the students through the worksheet and led a class discussion about the issues raised in the worksheet. We modified the standard Sokoloff-Thornton procedure so that there was only a single worksheet that emphasized finding the valid content of a student's intuition and refining it.

The students were not graded on their answers to either the RAD questions or the ILDs, but they were given participation points for doing them and were given homework and test questions to assess their understanding of the material discussed during ILDs.

Discussion and Laboratory: Each week students attended a discussion and laboratory section taught by a teaching assistant. These sections were limited to 20 students per section and met once a week for three hours. In the first hour the students had a discussion session and worked in groups of four on tutorial worksheets. Some of the

worksheets were adapted from the tutorial environment developed at the University of Washington<sup>vi</sup> to be more epistemologically explicit, while others were adapted from worksheets previously created at the University of Maryland.<sup>vii</sup>

During the second and third hours, the students worked on a reformed laboratory environment called *Scientific Community Labs*.<sup>viii</sup> These laboratories were non-traditional. First, instead of a lab manual with detailed instructions, students received a brief description of a particular setting and were asked a question whose answer was to be determined experimentally. Working in groups of four, they were expected to design and carry out an experiment to answer the question. Second, the laboratories focused on the process of doing science, rather than on physics content. Topics were chosen whose answers were “not in the book” or were covered much later in the course. The goal was to foster experimental exploration and discussions of “how do you know and why do you believe your results?”

Coherence: An important characteristic of the reformed class was the attempt to make the various parts epistemologically oriented and mutually supportive. The instructor and the teaching assistants frequently cross-referenced among homework, lectures, tutorials, and laboratories. Exam questions drew from and mixed information that the students had worked on in each of the class components.

## **2. Complete Transcripts of the Case-Study Episodes**

The names specifying the students in the transcripts are gender indicating code names.

### **The Discussion of the Three-Charge Problem**

**[Begins with a discussion of an earlier problem]**

**BONNIE**: Yeah, 2(b); what is the charge of  $q_1$ ?

**DARLENE:** OK, basically what I did was—is there a marker?

**ALISON:** Budget cut—no markers.

**DARLENE:** I might need that, so I'm going to leave this. I used this equation, like  $F = k \frac{q_1 q_2}{r^2}$ , for...

**BONNIE:** That's Coulomb's Law.

**DARLENE:** Yeah, the Coulomb's Law, or whatever, let me look at the problem actually, and basically you know that, I figured out what the charge difference would be. Like if  $q_1$  was attracted by like this this charge and this charge I would add them both together and that would determine what the net force was. So, basically for this interaction I just set values for everything, like I set this distance equal to .2 this one equal to .15 or something, and assigned these two a charge that was exactly the same and this charge like a little bit less—it doesn't matter. And, in the way it came out was that the one that has the smaller distance that this attracts it greater—has a greater force of attraction towards it. I mean—and it's pulling it like in a positive direction, because of the attraction it has, where this one had a smaller force and it's pulling it in a negative direction, so you add those two together it's going to determine a positive net force. Pulling it in the positive direction. Does that make any sense?

**CARLOS:** Yeah.

**DARLENE:** OK.

**CARLOS:** [to ALISON] You understand this stuff now?

**ALISON:** Huh?

**CARLOS:** How do you feel about that?

**ALISON:** EEAAHH?!

**DARLENE:** It's hard to explain, like you might just have to look at it.

**ALISON:** No, I think I agree.

**DARLENE:** Alright.

**ALISON:** I think I understand.

**CARLOS:** So, you're saying the force is going to be moving...?

**DARLENE:** Huh?

**CARLOS:** The force is going to be moving with what side?

**DARLENE:** To the right.

**BONNIE:** To the right.

**CARLOS:** So let's say this guy you move it here...

**DARLENE:** No it's saying that in the problem—ok, here's what you're starting with.  
Say it's like this. And, these two—these are like  $x$ .

**CARLOS:** Yeah.

**DARLENE:** Right. And, now there giving you a new situation, in which like say this is ok...ok...so the distance between it's changing, so this was  $x$  minus two and this is  $x$  plus two, it's gaining whatever this is losing, because the whole distance is staying the same. So, you just have to like determine that—basically like the way I figured it out is that you determine the forces between these two particles. This is big positive force.

**CARLOS:** Yeah. Yeah.

**DARLENE:** And, then when you determine between these two particles it's a smaller, it's a smaller value than this but because this is a negative term this is a positive it's pulling it in the left direction, which is the negative direction so it's a small negative. And, when you add like a big positive to a small negative it's will produce a positive force. Which is the net force pulling it this way. Does that make sense?

**CARLOS:** Alright.

**ALISON:** That makes more sense.

**BONNIE:** The diagram helps.

**DARLENE:** The diagrams...visual display.

**BONNIE:** It's aesthetically pleasing.

**[They turn to a discussion of the 3-charge problem – problem 2B]**

**DARLENE:** OK, so  $q_3$  there's no forces acting on it, or no net force?

**BONNIE:** No net force.

**ALISON:** Which means there are forces on it...

**DARLENE:** The charge  $q_2$  has a value...

**BONNIE:** We got 2A. B.

**DARLENE:** Oh, do you guys understand or do you want me to...

**BONNIE:** I understand.

**DARLENE:** [to ALISON] Do you?

**ALISON:** I think so.

**DARLENE:** Do you understand 2B? Yes, ok. So, let's go to two big B. Three charge blah blah blah.

**ALISON:** My reasoning with this one...

**DARLENE:** The charges  $q_1$  and  $q_2$  are fixed, the charge three, the charge is free to move. But, like it can increase or decrease in charge, but it's staying the same? Is that...?

**ALISON:** No.  $q_1$  and  $q_2$  are fixed in space.

**DARLENE:** Oh, distances?

**BONNIE:** Yeah. They're like stuck there.

**ALISON:** And, then  $q_3$  just happened to float along and is like chilling out by  $q_2$ .

**DARLENE:** OK, and then what's with the value of charge of  $q_1$ ?

**BONNIE:** That sounds like this should be an MCAT question or something. (6:55)

**DARLENE:** Yeah. Well, the distance between  $q_1$  and  $q_2$  and  $q_2$  and  $q_3$ , they're the same, right?

**ALISON:** Yeah. I'm assuming so, since they're both d.

**DARLENE:** I'm thinking that the charge  $q_1$  must have it's...negative Q.

**ALISON:** We thought it would be twice as much, because it can't repel  $q_2$ , because they're fixed. But, it's repelling in such a way that it's keeping  $q_3$  there.

**BONNIE:** Yeah. It has to—

**DARLENE:** Wait say that.

**ALISON:** Like— $q_2$  is— $q_2$  is pushing this way, or attracting—whichever. There's a certain force between two q, or  $q_2$  that's attracting.

**DARLENE:**  $q_3$ .

**ALISON:** But at the same time you have  $q_1$  repelling  $q_3$ .

**DARLENE:** How is it repelling when it's got this charge in the middle?

**ALISON:** Cause it's still acting. Like if it's bigger, than  $q_2$  it can still, because they're fixed. This isn't going to move to it's equilibrium point. So, it could be being pushed this way.

**DARLENE:** Oh, I see what you're saying.

**ALISON:** Or, pulled. You know, it could be being pulled more, but it's not moving.

**DARLENE:** Um-huh.

**ALISON:** So, we—we were thinking it was like negative two Q or something like that.

**BONNIE:** Yeah. Cause it has to be like big enough to push away.

**ALISON:** [to CARLOS](?)

**DARLENE:** Push away  $q_3$ .

**BONNIE:** Yeah, which we—which I figured out negative two.

**DARLENE:** Cause it's twice the distance away than  $q_2$  is?

**BONNIE:** Yeah.

**DARLENE:** I agree with that.

**CARLOS:** Yeah, I mean it kinda makes sense. This—

**ALISON:** Did you run that?

**CARLOS:** This one's positive.

**[off task for about 1 minute]**

**CARLOS:** (?) If this one—this one should be negative and this one could be negative, so it would just like repel it.

**ALISON:** That's true.

**BONNIE:** What?

**DARLENE:** But, it's ge...

**ALISON:** Well, it could...

**CARLOS:** Or, they both can be positive, they're just like repelling.

**ALISON:** It makes that—this problem impossible. If they're like—like if we have—maybe this is positive and these two are negative, or these two are negative and this is positive.

**BONNIE:** No, see the negative signs just mean the opposite of. So, like...

**CARLOS:** (?)

**DARLENE:** You don't even have to assign signs. Like...

**BONNIE:** Yeah. Whatever sign that  $q_2$  is,  $q_1$  has to be opposite and twice that.

**CARLOS:** OK.

**BONNIE:** So, it also has to be...

**DARLENE:** Why hey —why does it have to be opposite?

**ALISON:** But, not necessarily.  $q_1$  and  $q_2$  can both be negative since they're fixed and then  $q_3$  can be a really big positive.

**DARLENE:** But, if  $q_3$  were a big positive it'd be stuck to  $q_2$ .

**ALISON:** I mean...or, I don't know.

**DARLENE:** Like they'd all have the same charge.

**BONNIE:** Like...

**ALISON:** I guess that makes sense. Then you know  $q_2$  and  $q_3$  can't be...

**BONNIE:** Think of them as like constants. Like negative two and then this as a positive one and this as a negative one. And, then  $Q$  could be a negative or positive number. And, you just multiply by negative two. Or...one or whatever. I don't know. It makes sense to me.

**ALISON:** What time is it?

**DARLENE:** I don't know. I got to get out—right—

**BONNIE:** It's three twenty.

**DARLENE:** At three thirty I have to start writing my stuff down.

**ALISON:** I think I'm going to stick with my answer.

**DARLENE:** (?) Are you a TA also?

**TA:** Yes.

**DARLENE:** I have a question. I didn't know. OK on this problem, I feel like there's more than one possible answer.

**TA:** OK.

**DARLENE:** Like they don't tell you anything about the charges, right?

**BONNIE:** Yeah. They don't tell you anything about the charges. You just know that (11:16) this has—this feels no net force. So, if this one attracts this one, then this one also has to repel it.

**DARLENE:** But it's not like—I feel like this  $q_1$  doesn't have much of an interaction with  $q_3$ , because of  $q_2$  in the middle. Is that right to think that or does it still gonna have some effect on it?

**TA:** Why do you think that? I mean, what's your reason?

**BONNIE:** Like why is it not going to have an effect on  $q_3$ ?

**DARLENE:** I don't know. Maybe you're right. I guess like charge doesn't have to go in a horizontal line. It can go anywhere, right? And, this is free to move, so it can pull it this way. If it wanted to.

**BONNIE:** Yeah, but since it's in equilibrium, it's not going to.

**TA:** So, you're saying that this doesn't on  $q_3$ ?

**DARLENE:** No, it does.

**TA:** OK.

**DARLENE:** I just didn't think about it, right. OK.

**BONNIE:** So, do you understand how it works?

**DARLENE:** Yes.

**BONNIE:** OK.

**ALISON:** We always get the TAs over here and then have no point when they get here.

**DARLENE:** I think they all have the same—I think they all have—I know! I'm like, sorry. I think they all have the same charge.

**BONNIE:** You think they all have the same charge? Then they don't repel each other.

**DARLENE:** Huh?

**BONNIE:** Then they would all repel each other.

**DARLENE:** That's what I think is happening.

**BONNIE:** Yeah, but  $q_3$  is fixed. If it was being repelled—

**ALISON:** No, it's not.  $q_3$  is free to move.

**BONNIE:** I mean,  $q_3$  is not fixed. That's what I meant.

**DARLENE:** Right.

**BONNIE:** So, like...

**DARLENE:** So, the force of  $q_2$  is pushing away with is only equal to  $d$ .

**BONNIE:** Yeah, but then...

**DARLENE:** These two aren't moving.

**BONNIE:** Wouldn't this push it somewhat?

**ALISON:** Just because they're not moving doesn't mean they're not exerting forces.

**DARLENE:** I know.

**ALISON:** What do you think?

**TA:** Can I make a suggestion?

**DARLENE:** Uh-huh.

**TA:** You guys are talking about like a lot of forces and stuff. And, one thing I've suggested in previous semesters, if you write it down and say, what forces do you think are acting here, you can all talk about it.

**DARLENE:** Where did the marker go?

**TA:** That's a suggestion—a general suggestion that I might make.

**DARLENE:** I need this.

**ALISON:** You don't need that.

**DARLENE:** Huh?

**ALISON:** Do you need that?

**DARLENE:** Possibly.

**ALISON:** Oh! OK.

**DARLENE:** I don't know. I don't want to get rid of it.

**ALISON:** Tell me what the problem is. Do you need this?

**DARLENE:** No. Do you guys need this?

**TA:** May or may not help, I don't. If you decide you don't want to do this in the future...

**ALISON:** Alright. So, what are we doing?

**DARLENE:** Just draw it up there and then...I think it's just the fact that  $q_1$  and  $q_2$  are fixed, so you don't know what they would be doing if they weren't. You know what I mean?

**BONNIE:** Ah, I thought about that. I was like, oh, what if they weren't fixed, well of course they don't (?).

**DARLENE:** Right.

**BONNIE:** What?!

**DARLENE:** You're trying to figure out what  $q_1$  is, right?

**BONNIE:** Oh, yeah.

**ALISON:** Because this is in equilibrium, there's some force...

**DARLENE:** Pulling it that way and some force pulling ex—equally back on it.

**BONNIE:** Yeah.

**ALISON:** And, they're equal?

**BONNIE:** Yes.

**DARLENE:** Same with up and down. Not that that matters, really.

**BONNIE:** We'll just stick with...

**DARLENE:** Horizontal.

**BONNIE:** Yeah, one dimension.

**ALISON:** So, maybe this is pushing...

**DARLENE:** That's [ $q_2$ ] repelling and  $q_1$ 's attracting?

**BONNIE:** Yeah, it's just that whatever  $q_2$  is,  $q_1$  has to be the opposite. Right?

**ALISON:** Not necessarily.

**DARLENE:** Yeah.

**BONNIE:** OK, like what if they were both positive?

**ALISON:** Well, I guess you're right. They do have to be different, because if they were both positive...

**BONNIE:** Then, they'd both push the same way.

**ALISON:** And, if this were positive it would go zooming that way.

**DARLENE:** They would both push.

**ALISON:** And, if this were negative it would go there.

**BONNIE:** It would go zooming that way.

**ALISON:** And, if they were negative...

**DARLENE:** It would still—they'd all go that way.

**ALISON:** It would be the same thing.

**BONNIE:** Yeah, so whatever  $q_2$ —

**DARLENE:** So, they have to have opposite charges.

**BONNIE:**  $q_1$  has to be at least opposite  $q_2$ , and since it's twice as far away from  $q_3$  as  $q_2$ , it has to be...

**DARLENE:** Twice as big as the charge?

**BONNIE:** Yeah. Negative two  $Q$ , since it's twice as far away.

**DARLENE:** Negative two  $Q$ .

**ALISON:** Are we going to go with that?

**BONNIE:** I think it makes sense.

**DARLENE:** That makes...

**ALISON:** Well, I don't know, because when you're covering a distance you're using it in the denominator as the square.

**BONNIE:** Oh! Is that how it works?

**ALISON:** And (?) makes a difference.

**BONNIE:** Yeah, you're right.

**TA:** So, how do you know that?

**Al:** From the Coulomb's Law.

**BONNIE:** So, it should actually be negative four Q? Or what? Since it has...

**ALISON:** Cause we were getting into problems in the beginning of the problem with 2A A [the earlier problem], because I thought that like if you move this a little bit to the right the decrease for this would make up for the increase for this. But, then we decided it didn't. So, that's how I know that I don't think it would just increase it by a factor of two.

**DARLENE:** Uh-huh. I see what you're saying.

**ALISON:** I guess it would be four.

**BONNIE:** Yeah.

**TA:** So, what do we know—you drew some arrows there before. What were those arrows all about?

**DARLENE:** The  $q_3$  is being held in an equilibrium that's why it's not moving.

**ALISON:** Yeah, so there's some push and there's some pull that's equal.

**DARLENE:** Right, that's keeping it where it is.

**TA:** What are those pushing and pulls in terms of physics? Like...

**DARLENE:** Attraction and repulsion. Basically.

**CARLOS:** I said that you know if we—whatever force you know  $q_2$  exerting on  $q_3$  is  $q_3$  is exerting on  $q_2$ . I mean they're the same and equal in force. So, whatever force  $q_2$  is that's what  $q_3$  is gonna be, 'cause I suppose they're in equilibrium, right? They're not doing anything.

**DARLENE:** But,  $q_3$  can take into account what  $q_1$  is doing also.

**TA:** So, what forces does  $q_3$  react to?

**ALISON:** Both of these. Right?

**DARLENE:** I think so.

**TA:** Right, in general, an object only reacts to the forces that it feels.

**BONNIE:** Right.

**TA:** Not necessarily forces that it can exert on other things.

**DARLENE:** Uh-huh.

**ALISON:** So, (?)

**CARLOS:** Yeah, I mean  $q_3$  doesn't know anything about  $q_1$ , it only knows about  $q_2$ .

**TA:** Why do you say that?

**DARLENE:** Why?

**CARLOS:** Huh?

**TA:** [DARLENE is] asking why. Why doesn't  $q_3$  know about  $q_1$ ?

**CARLOS:** You know cause it's like, it—it cannot feel anything from  $q_1$ . It can only (17:34.1) feels something from  $q_2$ .

**ALISON:** I think charge is different, though. Like—like, like it's not like pushing. Well, it is pushing, but it's a different kind of pushing. You know what I mean?

**DARLENE:** Like—like.

**ALISON:** Like if I was—

**DARLENE:** Like a hydrogen molecule—think of it as if like water. I think water helps. Like cause y'know when...this is the oxygen and it's negative, and hydrogens are positive. Like if there was another water molecule coming...like this negative charge is felt by this. And—but it can come from anywhere. Like these negative charges can come this way. This positive charge attraction is not just like in one plane. It can come from anywhere. I think that's why like with  $q_3$  if it wanted to it could move towards  $q_1$ , depending on how it interacted, but it's chosen to settle by  $q_2$ . That's what you have to take into consideration. Like it could be anywhere.

**TA:** So, [DARLENE] you're saying that—[DARLENE] that's correct?

**DARLENE:** Oh, that's [ALISON]. I'm [DARLENE].

**ALISON:** That's [DARLENE], I'm [ALISON]. You're close though.

**TA:** [ALISON], OK.

**DARLENE:** It's alright.

**TA:** So, [ALISON]—if I understand this—[ALISON] you're saying that  $q_3$  can feel  $q_1$ ?

**DARLENE:** Sure. Yeah.

**TA:** And, [CARLOS] you're saying it can't?

**CARLOS:** I mean the way it's drawn there [DARLENE: It's deceiving] you're thinking the closest—the closest to  $q_3$  is  $q_2$ .

**TA:** Because like  $q_2$  is like in the way. So, it can't feel it from  $q_1$ .

**CARLOS:** Cause I mean like the way it's drawn, I mean but now I see what you're saying. And, again it could come from like anywhere and I mean changed my mind

now that she's said that. Y'know what I mean, yeah. That is like the way it's drawn there I would say I would say that, I mean like  $q_2$  has the strongest like force. It's keeping  $q_3$  in equilibrium. That's what the problem is saying, right?

TA: The problem is saying—

DARLENE: It doesn't say what's keeping it in equilibrium, it just says that it's in equilibrium.

CARLOS: Yeah.

ALISON: Well, you know that there's a balance of forces, so like...well, I don't know if  $q_2$  would necessarily be the stronger charge, because  $q_1$  has to cover some much more distance, which goes back to our point before.

DARLENE: Uh-huh. But, distance might not have anything to do with it.

ALISON: I think it does. I could be wrong, though. I don't know.

TA: So, let's think about example—

DARLENE: The greater distance away the smaller the force you have on it.

TA: did you guys do the thing with the tapes? [A tutorial on electric charge using Scotch "Magic" tape.]

ALISON: Yeah.

TA: You did the thing with the tapes, right?

DARLENE: Uh-huh.

TA: So, if you had the tapes far away did you see them attract to each other?

DARLENE: No.

TA: If you brought them close to each other did you see them attract?

DARLENE: Uh-huh.

CARLOS: Oh, yeah.

TA: So, do you think distance matters?

CARLOS: It does.

DARLENE: Yeah, it does. But, like I think in that case, though,  $q_1$  going to have a small attraction to  $q_3$  because it's so far away. But, I mean, from the way  $q_3$  is just settled there, like if  $q_3$  was between  $q_1$  and  $q_2$  cause it could have been, you know, like it could go where ever it wanted. But, it chose to be there, so  $q_1$ 's having a weaker interaction on it. (20:25.7)

TA: But, one thing—I think...

**DARLENE:** I don't know.

**TA:** [DARLENE] was saying earlier that the forces had to be equal, is that what you were saying?

**ALISON:** Right. I think  $q_1$  is pushing. It's got to cross more of a distance, so it's pushing like—its charge is bigger to cross that distance. Whereas, this doesn't have to go as far.

**DARLENE:** Well, we just concluded from 2A that that's not true.

**BONNIE:**  $q_1$  could be pulling and  $q_2$  could be pushing.

**ALISON:** Yeah, I mean which ever.

**BONNIE:** Yeah.

**ALISON:** It's doing some action and then  $q_2$  —  $q_2$  doesn't have to exert as much force because it's closer. I think that's exactly what we talked about in two.

**BONNIE:** Yeah. Which is why...

**DARLENE:** No, I think it exerted more force, when it was closer. The interactions were stronger.

**ALISON:** Well, it's less of a charge, but it exerts—because it's less of a charge it can exert more force over that smaller distance.

**DARLENE:** Less of a charge?

**ALISON:** Like it's smaller distance so it doesn't need as much charge to push with the same force.

**TA:** Do you guys buy that? [BONNIE is shaking her head and saying, 'yeah'.]

**BONNIE:** I understand. Yeah.

**ALISON:** I'm not explaining it as well as I think I should be, but...

**DARLENE:** This is a frustrating problem.

**BONNIE:** This problem looked so easy.

**DARLENE:** I know.

**BONNIE:** It's definitely an MCAT problem.

**DARLENE:** Huh?

**BONNIE:** It's definitely an MCAT-type problem.

**DARLENE:** Yeah.

**TA:** So, yeah, where are we at—at this point in the problem? I'm...so...

**DARLENE:** Still back at square one. I just feel like I don't know anything.

**ALISON:** We've established that there are forces acting on it.

**TA:** Let me try and summarize things that I've heard.

**DARLENE:** OK.

**TA:** I heard that  $q_1$  is at a greater distance, so someone said that the charge on it had to be greater.

**BONNIE:** Yeah.

**TA:**  $q_2$  is at a shorter distance compared to  $q_1$ , so it could have smaller charge on it.

**ALISON:** Right.

**TA:** Everyone agrees on that. Those are things (22:15) that were said. Do we agree on these things?

**DARLENE:** To an extent.

**TA:** OK, you said  $q_1$  was negative, because—so if  $q_3$  was positive  $q_1$  would be negative it would pull it. It would—it would sort of pull it to the left. And,  $q_2$  would push it to the right.

**ALISON:** Right. Or, it could be—yeah.

**DARLENE:** Just depending on how the charge—it—that doesn't necessarily have to be how it is. Like—

**TA:** So, what other options do we have?

**DARLENE:**  $q_1$  could be negative.

**ALISON:** These two could be positive, too.

**DARLENE:** OK [tentatively].

**ALISON:** Because this would still feel the attraction to the positive, but it wouldn't be able to go all the way to the positive, because of the push from  $q_1$ .

**BONNIE:** What?

**DARLENE:** Like, OK, I think I see what you're saying.

**ALISON:** Or, like these—it could be—

**DARLENE:** Like,  $q_1$  —  $q_2$  and  $q_3$  could have the same charge.

**BONNIE:** Uh-huh.

**DARLENE:** So, they repel each other. And,  $q_1$  could have the opposite charge of  $q_2$  and  $q_3$ , which would attract it, but since it's so far away it doesn't come any closer to it.

**ALISON:** Or,  $q_2$  and  $q_3$  could have opposite charges and it could—it could be attracting, but it's still—yeah—but it's still like pushing each other.

**DARLENE:** Two like big (23:17.5) B, the second part of 2. I think there's a variety of answers to this question.

**BONNIE:** Yeah.

**DARLENE:** So, I'm going to say ... like  $q_2$  and  $q_3$  are repelling, and  $q_1$  and  $q_3$  are attracting.

**ALISON:** But you don't know that.

**DARLENE:** You don't, but you can assign values that way.

**BONNIE:** We can just say that the mul—we could give like two different answers.

**ALISON:** Does that even answer the problem?

**DARLENE:** It's asking (23:50) you what the—

**BONNIE:** What we're trying to figure out is what's the coefficient for  $q_1$ . Like, is negative two or negative four, or four or six. That's what (?) can't figure out.

**DARLENE:** What must the charge  $q_1$ —what value must the charge  $q_1$  have?

**BONNIE:** Yeah.

**TA:** So, do you agree—

**DARLENE:** Like Coulomb's law, like I'm trying to use that.

**ALISON:** I don't see why it has to be negative.

**BONNIE:** Well, no.

**DARLENE:** It doesn't have to be negative. It could be positive and  $q_2$  and  $q_3$  could be negative.

**BONNIE:** Yeah, well the negative sign just means it's the opposite of whatever  $Q$  is.

**TA:** What's the value of  $q_2$ ? Do we know?

**ALISON:**  $Q$ .

**TA:** Is it positive or negative?

**BONNIE:** Yeah.

**ALISON:** It doesn't give positive or negative.

**DARLENE:** It tells you  $q_2$  is equal to—Oh!

**ALISON:** I mean you could take it as being positive, but (?) coefficient—oh.

**CARLOS:** Like, negative charges are like lighter than positive charges, so it has the tendency to like move, y'know, like have more electrostatic.

**DARLENE:** I have no idea.

**TA:** Why do you say that? I mean if you're thinking about maybe electrons and protons you might think negatives are lighter.

**BONNIE:** Just like electricity.

**TA:** In general, it doesn't necessarily have to be that way.

**CARLOS:** So,  $q_3$  could be positive or negative than.

**BONNIE:** Yeah,  $q_3$  could be positive or negative, but it looks like  $q_1$  is always the opposite of whatever  $q_2$  is.

**TA:** So, I have a question. Does it hurt us if we assume that  $q_2$  is some charge, positive or negative, it tells us it's  $Q$ , can we just assume that it's one of them?

**DARLENE:** Yeah, that's what I'm trying to do.

**TA:** And, like  $q_3$  is one of them and then figure out which one  $q_1$  had to be.

**DARLENE:** Yep.

**ALISON:** OK.

**DARLENE:** So, I'm going—I'm going to assume that  $q_2$  is—

**BONNIE:** One.

**ALISON:** Positive.

**DARLENE:** Is positive.

**BONNIE:** Positive?

**DARLENE:** And,  $q_3$  is positive, too. So, they repel each other. And, that's going to account for this part of the equilibrium [right push]. So, then you got to account for this part [left push] of the equilibrium, which is what  $q_1$  is going to do. And, that's going to be...it's going to be opposite—have the opposite effect as  $q_2$ , so it's going to be negative something  $Q$ .

**BONNIE:** Yeah. If you draw it the other way it'd still be negative something  $Q$ .

**DARLENE:** Yeah.

**CARLOS:** Put the charge up there.

**BONNIE:** That's what we're trying to figure out; how much the charge could be.

**DARLENE:** We're trying to figure out—

**CARLOS:** So, you're saying that  $q_3$  and  $q_2$ , they're positive both?

**DARLENE:** Yes.

**CARLOS:** Two and three are positive, right?

**DARLENE:** Yes. That's why I write my—

**ALISON:**  $q_2$  is pushing away, but  $q_1$  is pulling.

**DARLENE:** Yes, but we—it's pulling by how much? Charge — what...How much is the question.

**ALISON:** Basically, all we have to figure out is how is this distance different from this distance.

**BONNIE:** Yeah.

**DARLENE:** But...

**BONNIE:** Both the same distance, but how does that effect the charge?

**DARLENE:** Like it's twice and they give a distance.

**BONNIE:** Yeah. So, if you double the distance how does that effect the charge, like does it—do you have to have the charge twice as big or four times big?

**DARLENE:** Where is that other problem? Three times as far apart as they were now what is the magnitude of the force?

**BONNIE:** I think it should be four times.

**DARLENE:** If it's three times as far apart it's...you divide...uh! I think it's  $Q$  over two.

**BONNIE:**  $Q$  over two? So, if you think of it as half the force of  $q_2$ .

**DARLENE:** Look at this one.

**BONNIE:** Is this one you're talking about?

**DARLENE:** Uh-huh. If you increase the distance that they are from each other it's decreasing by the same amount. I thought it was four (?), but they said it was (?). I don't know why. Just three times...does it matter? [talking to another table] I'm looking this one. Number three, isn't that like the same thing?

**ALISON:** Three was an estimation problem.

**DARLENE:** No, no with the  $q$  and four  $q$  and all that, you know how there was this question that asked when you move the charges three times further apart than they originally were, what the resulting force is.

**ALISON:** OK.

**DARLENE:** And, you said it was—we said it was four (?)—the charge would be like  $q$ ,

or nine, but it would get three times as far apart. Why it's not three I don't understand, but that's alright. So—

**ALISON:** Well, 'cause in the equation you square this—the distance between them. Like if you're multiplying by three...

**DARLENE:** Oh! So, I would think this one would be  $q$  over four—negative  $Q$  over four. Cause it's twice as far away, opposite charge. Does that make sense?

**ALISON:** But, then it's a smaller charge than this.

**BONNIE:** Yeah.

**ALISON:** So, I don't understand how it would be pushing three or pulling three whatever it's doing.

**DARLENE:** Wait, let me see, where's the pen?

**BONNIE:** You can use the eraser.

**DARLENE:** Let me erase part of this. This is positive, this is positive. Negative, this is  $d$  and this is  $d$ .

**ALISON:** [to CARLOS] I'm sorry.

**CARLOS:** [inaudible]

**ALISON:** But,  $q_1$  and  $q_2$  are fixed...

**DARLENE:**  $q_3$  can move.

**ALISON:** And, then, right—according to the diagram I'm assuming that these distances are the same, cause they're using the same...variable.

**CARLOS:** Yeah.

**DARLENE:** See what I did? I changed the denominator part.

**BONNIE:** So... (32:11) we just said it's  $4Q$ ?

**DARLENE:** I think it's negative  $Q$  over four.

**BONNIE:** What?

**DARLENE:** I think it's negative  $Q$  over four.

**BONNIE:** Why would it be divided?

**DARLENE:** Well, you're using this, like Coulomb's law. This would be like the force between—

**ALISON:** I don't know, because it's exerting the same force that this is exerting and this one like if you put it in and you put in one you'll get  $k q q$ , [DARLENE: Oooh!] but to get—to get one with that you have to do negative four  $Q$  up here and then the four

would cancel out.

**BONNIE:** Yeah, so that way the answer will be the same both ways.

**DARLENE:** Wait.

**BONNIE:** The same—

**DARLENE:** Say that one more time.

**ALISON:** Alright. This exerting a force...

**DARLENE:** Yep.

**ALISON:** And, then the force this is exerting this is feeling the same force. OK?

**DARLENE:** Same magnitude as what—

**BONNIE:** Yeah, same magnitude.

**DARLENE:** Yeah, OK.

**ALISON:** So, then they cancel for it to be in equilibrium.

**DARLENE:** Right.

**ALISON:** So, then say this is between two and three. Alright, you ignore—you make the distance one. That would give you constant times you know the two charges.

**DARLENE:** Uh-huh.

**ALISON:** So, then if we go by your reasoning where you double the distance it would be two. So, you have all this under four.

**DARLENE:** Yep.

**ALISON:** So, it's—

**DARLENE:** But, you have to have four on top to cancel it.

**ALISON:** Right.

**DARLENE:** That, so it's negative four Q.

**ALISON:** [to CARLOS] Does that make sense?

**CARLOS:** Yeah, it sort of makes sense.

**DARLENE:** All that work for like a two second answer.

**CARLOS:** You know like the calculation's saying and it makes sense, but y'know, it's like is it right?

**ALISON:** [talking to some else at a different table.]

**DARLENE:** OK, I get it.

**ALISON:** Go for it.

**DARLENE:** Alright. We're saying that  $q_2$  and  $q_3$  have the same charge. So, this is repel...so this is pushing  $q_3$  this way, and since  $q_3$  is in equilibrium something's got to be pulling it this way; and that's gotta be  $q_1$ . So, if—so like say, say that like this distance or whatever is equal to one, like cause each of these is the same amount of distance between the two particles, from what the diagram said. So, these equal to one when you're doing like the distance between like  $q_2$  and  $q_3$  you get like some value over one. But, when you add these two together you get two as like when you're—the readings between  $q_1$  and  $q_3$  is two. And, when you have that over—and you plug it into that equation your distance is  $q$ —is two squared, which is four, so in order to like make this go away and equal to one, so that these two forces can be equal, so that this equilibrium holds true, you have to multiply by some multiple of four on top to cancel.

**TA:** You all agree with that?

**BONNIE:** Yeah.

**TA:** OK.

**DARLENE:** I don't know how I'm going to write this out though, in like two lines.

[off task for 30 seconds]

**ALISON:** OK, I'm done with this problem.

**DARLENE:** What did you write?

**ALISON:** Negative four  $Q$ . And, then I did like something like what I just said. Like I set them equal to each other and put an  $x$  in front of the big  $Q$ . So, like to make these equal you have to have a four in the numerator.

**DARLENE:** OK. I don't know how to write this.  $q_3$  and  $q_2$  are positive, so  $q_1$ ...

**CARLOS:** So, you think it's going to be negative four  $Q$ , huh? In—in-ah— $q_2$  is it four  $Q$ ?

**ALISON:**  $q_2$  is  $Q$ , and then distance increases by a factor of two, so based on whatever reasoning with that, we figured it's going to increase by a factor four.

**DARLENE:** Four times the im—it must exert four times the amount force as  $q_2$ ?

**ALISON:** The charge is going to be...

**DARLENE:** Four times the amount of charge as  $q_2$ ?

**ALISON:** Sure.

**CARLOS:** So,  $q_2$   $q_3$  you'd say they're—they're—they have a force of two?

**ALISON:** Well, between  $q_2$  and  $q_3$  you have this, and then between  $q_1$  and  $q_3$  this is kinda how I wrote it.  $q_3$  you have...

**DARLENE:** I just said assuming that  $q_2$  and  $q_3$  are positive, so  $q_1$  is negative.  $q_1$  must exert four times the amount of charge as  $q_2$ , [sic] so that the  $F$   $Q$ , force of  $q_2$  on  $q_3$  and force of  $q_2$ — $q_1$  on  $q_3$  are equal, helping  $q_3$  stay in equilibrium. Is that enough?

**BONNIE:** You basically covered it.

**DARLENE:** OK. What do you have a problem with number three?

**BONNIE:** I don't know where to start.

**DARLENE:** I just go back (?).

**BONNIE:** Like I assuming we're using Coulomb's law, that's the only law that we've been taught. But, I'm not exactly sure how to use it. Like...

**DARLENE:** Well, the—the balls aren't moving, right? So, what does that mean?

**BONNIE:** They are—the net force—like they in equilibrium.

**DARLENE:** Uh-huh. So, the net force is what?

**BONNIE:** Zero.

**DARLENE:** Right.

**BONNIE:** So,  $F$  would be equal to zero for Coulomb's law?

**DARLENE:** No. No. That—that's what I thought at first. But, the Coulomb's law doesn't tell you the net force, it just tells you how one's acting on the other. So, if you added the two together it would be zero. Does that make sense?

**BONNIE:** Oh, the force on one

**TA:** What did you do there?

**ALISON:** What did I do there?

**TA:** Yeah, can I ask?

**ALISON:** Alright, so because this isn't moving the two forces that are acting on it are equal. The push and the pull. So, the  $F$ —I don't know if this is the right  $F$  symbol—but, the  $F$   $q_2$  on  $q_3$  is equal to this. And, then the  $F$   $q_1$  on  $q_3$  is equal to this, because the distance is twice as much, so it would be four  $d$  squared instead of  $d$  squared.

**TA:** OK.

**ALISON:** And, then I used  $xQ$  like or you can even do—yeah— $xQ$  for the charge on  $q_1$ , because we know in some way it's going to be related to  $Q$  like the big  $Q$  we just gotta find the factor that relates to that.

**TA:** OK.

**ALISON:** Then, I set them equal to each other, and I crossed out like the  $q_2$  and the  $k$  and the  $d$  squared and that gave me  $q$  equals  $xQ$  over four. And, then  $xQ$  equals  $4Q$ ,

so  $x$  would have to be equal to four. That's how you get it's  $4Q$ .

**TA:** How did—why did you set it equal?

**ALISON:** Because, they're equal charges. [sic] Like these two have to cancel each other out for this to be in that equilibrium.

**BONNIE:** Both should equal.

**TA:** Do you guys buy that?

**DARLENE:** Yeah.

**BONNIE:** Well, shouldn't it be—well equal and opposite, but...

**ALISON:** Yeah, you could stick the negative.

**BONNIE:** Yeah.

**DARLENE:** I didn't use Coulomb's equation, I just—but it was similar to that.

**BONNIE:** That's a good way of proving it.

**DARLENE:** Uh-huh.

**BONNIE:** Good explanation.

**ALISON:** Can I have my  $A$  now?

**BONNIE:** Yeah, two weeks into the course.

### **The Discussion of the Air-Pressure Problem**

**MARTHA:** We're saying that the pressure...

**SUSANNAH:** Right.

**MARTHA:** Well pressure's supposed to be higher at the bottom, isn't it?

**SUSANNAH:** Hmm?

**MARTHA:** Pressure is supposed to be higher at the bottom.

**SUSANNAH:** I think there's more at the bottom, because the thing, because the gravitation.

**MARTHA:** And, there's pressure pushing down on it.

**SUSANNAH:** Um-huh.

**MARTHA:** OK.

**SUSANNAH:** Pressure's equal to the radius times the moles of the gas times the temperature divided by the volume. So, what we need to do, we know the pressure find the volume from this. Density is equal to...

**MARTHA:** Are you using  $pV$  equals  $nRT$ ?

**SUSANNAH:** Huh?

**MARTHA:** Are you using  $pV$  equals  $nRT$ ?

**SUSANNAH:** Yeah, or yeah.

**MARTHA:** Or.

**SUSANNAH:** Or  $p$  equals  $R$  times  $nT$ ...

**MARTHA:** Over  $V$ .

**SUSANNAH:** Over  $V$ .

**MARTHA:** We know the pressure.

**SUSANNAH:** We know the pressure. But we need to take the density to volume. Density is equal to...

**MARTHA:** Oh, we have the density.

**SUSANNAH:** Yeah, yeah, but that doesn't matter we need the volume.

**MARTHA:** Oh, what did I just say?

**SUSANNAH:** Density is equal to volume over what mass, or something?

**MARTHA:** Density equals mass over volume.

**SUSANNAH:** Hmm?

**MARTHA:** Density is equal to mass over volume.

**SUSANNAH:** Is equal to mass over volume.

**ALICE:** It's over, it's over.

**SUSANNAH:** OK. So, if let's say it's equal to mass over volume, then [to another student] yeah. No I just found the formula to do it. So, this is equal to mass over volume, then the mass is equal to. So, basically we just found the formula that  $p$  is equal to the radius times the moles times the temperature over the volume. So, if we have the density we can find the volume.

**MARTHA:** Is  $R$  the radius?

**DAPHNE:** I don't think  $R$  is the radius.

**SUSANNAH:** It's not? The radius of the...

**MARTHA:** R isn't radius. R is...

**SUSANNAH:** Or, whatever R is.

**DAPHNE:** Some number.

**MARTHA:** It's not radius.

**SUSANNAH:** Is it a constant?

**ALICE:** Yeah, it's a constant. It's a constant.

**MARTHA:** It's a constant. It's...

**SUSANNAH:** Awesome, one less thing for us to find.

**MARTHA:** Oh, here it is, universal gas constant (?) 8.31 Joules

**SUSANNAH:** 8.31 Joules per mole?

**MARTHA:** Yeah.

**SUSANNAH:** OK.

**MARTHA:** No, joules over moles times Kelvin.

**SUSANNAH:** Times Kelvin. OK.

**MARTHA:** So, R is...

**SUSANNAH:** So, if the mass of the gas...we don't know. The density of air.

**ALICE:** I don't know...

**SUSANNAH:** Wait do we know the mass of it?

**MARTHA:** Do need the mass of the dormitory room?

**SUSANNAH:** No, we need the mass of the air, right? Of the gas.

**MARTHA:** Well, we know that density times volume equals mass, so all we need is the volume. [DAPHNE leaves] All we need is the volume, because we know that density times volume equals mass. And, we have the density, so all we need is the volume.

**SUSANNAH:** Yeah, but in order to find volume we need to know the mass.

**MARTHA:** The mass, exactly. Oh, no you can displace for it.  $V$  like instead of  $d$  equals  $M/V$ . [sic] Do  $d$  times  $V$  equals  $M$ .

**SUSANNAH:** Yeah, but...

**MARTHA:** We don't know the volume, that's there any other way.

**SUSANNAH:** But, we need to know it.

**MARTHA:** And, we need to know the volume...to get...

**SUSANNAH:** It's...[TA comes over] OK.

**MARTHA:** We are stuck on four.

**SUSANNAH:** We're doing number four.

**TA:** I heard, dah dah dah dah four.

**MARTHA:** We are stuck on number four.

**SUSANNAH:** We're on number four.

**TA:** You're stuck on four. Is this four, you're all doing the same thing?

**MARTHA:** Yeah.

**TA:** Alright, I'm going to read this for a moment. Oh, yes.

**SUSANNAH:** We have a couple of ideas going on.

**MARTHA:** Yeah.

**TA:** Ok, tell me your ideas.

**SUSANNAH:** OK, so we know um the formula for pressure.

**TA:** OK, what is it?

**SUSANNAH:** It's equal to the constant times the number of moles of the gas times the temperature of the gas over the volume.

**TA:** OK, that is a formula for pressure.

**SUSANNAH:** That is a formula for pressure?

**TA:** That's correct.

**MARTHA:** And, we know R, because R's a constant.

**TA:** Yes.

**MARTHA:** We can find V by using  $\rho$  equals  $M/V$ .  $M$  over  $V$ .

**TA:**  $\rho$  equals  $M$  over  $V$ . OK.

**MARTHA:** Right, exactly.

**TA:**  $p$  is pressure,  $\rho$  is density. I'm trying keep 'em straight in my head. Alright, go ahead.

**MARTHA:** Temperature...is that an estimation.

**SUSANNAH:** No. I think we're--are we supposed to use  $pV$  equals  $NkT$ ? What is  $N$ ?

**MARTHA:**  $nRT$ , is that what you're saying?

**SUSANNAH:**  $nRT$  is pressure...

**TA:** Ok, instead of  $nRT$ ?

**MARTHA:** Yeah, it's the same thing isn't it?

**TA:** So, you're changing which constant you use and what  $n$  is.

**MARTHA:** Oh.

**TA:** It's still the same number of things to be found, or know. Um.

**SUSANNAH:** Yeah, we still need to...

**TA:** Ok, so you just said, ok--

**SUSANNAH:** We need to figure out--we need to figure out the mass of--

**TA:** The mass?

**MARTHA:** The number of moles.

**SUSANNAH:** Of the mol--the mass of the air in the room in order to determine the volume. And, if we know the mass, then we can solve for how many moles it is. And, I'm assuming it's room temperature, but it doesn't specify.

**MARTHA:** Oh, good point. I was like what's the temperature.

**SUSANNAH:** So, I'm assuming it's 37 degrees Celsius, which goes to 273, right?

**ALICE:** Yeah, that's 273.

**TA:** Alright, so you're saying that you know the temperature and you know the--

**SUSANNAH:** Well, I'm assuming it's room temperature since it's not specified.

**TA:** Well, the question says under normal conditions.

**MARTHA:** So, yeah.

**TA:** Normally, what is a room? Room temperature. Ok, so you know the temperature you know this constant  $R$  do you know the volume?

**SUSANNAH:** No.

**MARTHA:** No, we can find it though.

**TA:** How?

**MARTHA:** We're doing mass over density, but we need to know the mass.

**SUSANNAH:** Oh, doh!

**TA:** So, you would need to know the mass. OK.

**SUSANNAH:** One kilogram per...

**TA:** It's says um consider a dormitory room and they tell you the density, so you're saying if all--if I knew the mass I could find the volume.

**MARTHA:** Right.

**SUSANNAH:** Well, it's one kilogram per for meters cubed, so it's kind of easy.

**TA:** That's the density?

**SUSANNAH:** Yeah, but that's kind of giving it to us easy, right, 'cause it's...

**MARTHA:** It's saying that mass is one, one kilogram. Is that what you're saying?

**SUSANNAH:** One kilogram per one meter cubed.

**TA:** Right, so if you lived in a room that was this big, one meter cubed there would be one kilogram of air there.

**SUSANNAH:** Yeah.

**TA:** I don't think you live in a room that big.

**SUSANNAH:** Yeah, I feel silly. OK. So, it's one kilogram...

**TA:** So, what um...

**MARTHA:** So, the mass is one kilogram, is what you're saying?

**TA:** Would you agree with me this is an estimation problem.

**SUSANNAH:** Um.

**MARTHA:** Yes.

**TA:** OK.

**SUSANNAH:** To a certain extent, yeah.

**TA:** What this problem is about a dorm room. How big is a dorm room?

**SUSANNAH:** Oh!

**MARTHA:** Not big at all.

**SUSANNAH:** He gave it in another problem. Like another homework.

**MARTHA:** (?)

**TA:** So, let me ask you another question. You're trying to figure out what is the mass so you can find the volume. Is there another way that you could just tell me what the volume is?

**SUSANNAH:** One meter cubed.

**MARTHA:** Yeah.

**TA:** That's this big. We're talking about a dorm room. What's the volume of a dorm room?

**SUSANNAH:** What would make it--what would make everything one. Oh! Would it be a hundred? Or, a thousand?

**MARTHA:** A thousand that's really big.

**SUSANNAH:** A hundred maybe?

**TA:** Alright, ok.

**SUSANNAH:** 'Cause I'm looking what's going to make this equa--what's going to make this num--what's going to make it one. You know.

**TA:** Let me jump in again. You're trying to make numbers work out, instead of thinking. Just STOP and think for a moment.

**SUSANNAH:** OK.

**TA:** What's the volume of a room?

**MARTHA:** Twenty by twenty by twenty.

**TA:** OK, how much is that?

**ALICE:** Yeah.

**MARTHA:** That's 20...

**TA:** Right, ok and those are twenty what?

**MARTHA:** Twenty...

**ALICE:** Feet cubed.

**TA:** Twenty feet. OK, you're saying twenty feet by twenty feet by twenty feet. You have twenty feet high ceilings?

**MARTHA:** Twenty, yeah.

**TA:** Oh, that's nice, but alright. So then you have some volume and feet cubed and you probably want to change it to meters cubed, but...you just told me what the volume is.

**MARTHA:** Twenty feet cubed?

**ALICE:** No, it's twenty cubed.

**TA:** Twenty cubed.

**ALICE:** Feet cubed.

**TA:** Right.

**MARTHA:** Ok. So, that's the volume?

**ALICE:** That's the volume of the room.

**MARTHA:** So, it is an estimation problem.

**ALICE:** I mean twenty up is...

**TA:** Well, there's parts of this problem that directly say estimate this and estimate that, so I think estimating how big a room is seems totally acceptable.

**SUSANNAH:** I think this is on the last homework that he gave like an estimate of like a dorm room.

**DAPHNE:** You guys are estimating the room.

**TA:** OK, so now, I want to...ask you another question now before you continue.

**MARTHA:** OK.

**TA:** Um, you had a formula for pressure and so if you know the constant and the temperature and the volume and the number of moles you could find the pressure.

**MARTHA:** Do we know the number of moles, oh, we can find it by doing with using the density and the volume.

**SUSANNAH:** But, we need to know the change in pressure.

**TA:** Well, yes. There you go. The question says, what's the difference in pressure between ceiling and the floor.

**MARTHA:** We can find both.

**TA:** Well, ok, so what's...

**SUSANNAH:** Right.

**TA:** So, you could--one way of doing that is to find the pressure at the ceiling and the pressure at the floor and take the difference. OK, the--

**SUSANNAH:** But, using that formula how would that formula vary from either, it wouldn't.

**TA:** But, with the formula you're using it just gives you one pressure. Just the pressure of the room.

**MARTHA:** The room.

**TA:** So, that's not, so you don't know if that's supposed to be ceiling or floor or is that just the average pressure in the room and really there's no difference. So, that doesn't seem to be very helpful.

**MARTHA:** At all.

**TA:** So, is this the only thing you know about pressure? What else do you know about pressure?

**MARTHA:** That it increases as you go down.

**SUSANNAH:** I think it increases as you go down, 'cause it's like pushing it together.

**MARTHA:** Compressed, it's more compressed.

**TA:** OK, depending on what? (?)

**MARTHA:** Density?

**TA:** OK. Alright, that's fine, um, I can believe it depends on density. Only density? Or you think...

**MARTHA:** Um, well you think about a person swimming.

**TA:** OK.

**MARTHA:** A scuba diver.

**TA:** Right.

**MARTHA:** Volume would depend, too. The volume of water increases as you go down. No, it doesn't...well, on top of you.

**TA:** How much water on top of you changes, right. OK. So, I think you've done those kind of problems or looked at them in class or something and how did you figure out the pressure...that the scuba diver felt? Like, let me ask this, if the scuba diver is fifty feet under water he feels a certain amount of pressure. If he's a hundred feet under water he feels a certain amount of pressure. Are those pressures the same?

**MARTHA:** No, there's more.

**TA:** They're different?

**MARTHA:** They're different.

**TA:** OK. How do you figure out what this pressure is [fifty feet] and this pressure is [a hundred feet]?

**MARTHA:** Buoyant force?

**TA:** OK, that could be true. That could work.

**MARTHA:** Some way or the other.

**TA:** I don't know. I have all of the equations memorized, so I don't if what the relationship is between the pressure and the buoyant force, but it's something to think about. Um, so what...I'm going to look at your book for a moment.

**MARTHA:** Alright, it's not mine.

**TA:** Oh.

**MARTHA:** So, this is kind of (?).

**TA:** Do you guys have your class notes? I mean, I don't--I'm not sure what you've done in class.

**SUSANNAH:** He just started talking about it.

**MARTHA:** I don't think many people were paying attention, he said that it wasn't important for the final, so...

**SUSANNAH:** Well, I was because I had read the problem and...

**MARTHA:** Oh.

**TA:** He said that...

**SUSANNAH:** He just started talking about it.

**TA:** About pressure? You've been on pressure for a little while, right?

**MARTHA:** Yeah.

**TA:** OK.

**MARTHA:** Basically, done  $pV$  equals  $nRT$ .

**TA:** That was the recent thing he did?

**MARTHA:** Yeah.

**TA:** So, but that's the thing that this is not useful for this problem.

**MARTHA:** At all.

**TA:** So, this problem is probably about stuff you did on pressure before that. Sort of the basic ideas of what is pressure is this stuff.

**SUSANNAH:** Man, he started deriving formulas and like--

**MARTHA:** Yeah, he went all crazy.

**SUSANNAH:** And, I couldn't follow any more.

**TA:** So, did you write down stuff? (15:11)

**SUSANNAH:** What made sense to me.

**TA:** OK. Um, so anything in there about pressure? Do you remember anything he said about pressure? What do you know about pressure?

**SUSANNAH:** Well...it...that we have pressure because we have a whole bunch of molecules being compressed into one area. And, they're all bouncing off of each other.

**TA:** OK.

**SUSANNAH:** And, they want to be individual, they don't want to be...

**TA:** Right.

**SUSANNAH:** Compressed. So...

**TA:** So, that's why we have pressure. Now, how do we figure out how much pressure there is for that situation?

**MARTHA:** The pressure in general?

**TA:** Yeah, whether it's some volume of water or air in the room.

**SUSANNAH:** Well, we need to know how much--how much is in that that that area, so the volume...

**TA:** OK, OK, you have to know the volume, alright.

**SUSANNAH:** You need to know area...

**MARTHA:** Area?

**SUSANNAH:** Don't--don't we need--no, we need to know volume.

**MARTHA:** We need to know all that stuff from that equation,  $pV$  equals  $nRT$ . Don't we? We know the  $R$ .

**TA:** (16:46) So, that would be one way of finding pressure. There are other ways as well. That you guys--that I'm very much assuming he's already talked about in class before this. And, I'm pretty sure about that because I know he talked about buoyant force and it's--you know--I'm assuming that when he talked about buoyant force he also talked about um pressure. So, if we go back here to when you first talked about pressure. This the definition of pressure, you guys did that in class right?

**MARTHA:** Hmm-uh.

**TA:** OK. UM. This is sort of what we just talked about pressure different depths in water. OK. I think...

**SUSANNAH:** We need a change in pressure formula.

**TA:** Alright, let's go back to this. Um, can you write on the board, the definition of pressure.

**SUSANNAH:** Pressure is a constant...over...

**TA:** OK.

**MARTHA:** V.

**SUSANNAH:** V.

**TA:** Alright you just wrote the ideal gas law.

**SUSANNAH:** Ah-huh.

**TA:** Which is a nice thing. But, I said what's the definition of pressure.

**SUSANNAH:** But it's not what we want--we want the P equals the force over area.

**TA:** OK. Erase the other thing. We already tried that it didn't work. [talking about erasers] Alright, so what is the force we're worried about in this sort of situation. I think you said that earlier.

**MARTHA:** Force of the air. Force--what did I say before? The buoyant force.

**TA:** I don't know...ok, buoyant force. What--how do you know what the buoyant force is? What's the definition of buoyant force?

**MARTHA:** How much it displaces.

**SUSANNAH:** The entire...

**TA:** Say again.

**MARTHA:** How much water it displaces.

**TA:** OK.

**MARTHA:** Is increased (?) um, the buoyant force...

**SUSANNAH:** The weight of the displaced water.

**TA:** The weight of the displaced water, OK. So, if we want to kind of write an equation for what this buoyant force is, so how do you find weight?

**SUSANNAH:** You have...

**MARTHA:** Is that for weight?

**SUSANNAH:** No, I'm sorry. I'm confusing myself. It's ah...times gravity.

**TA:** OK, that's weight. Now that mass you wrote there is the mass of the water, OK? A lot of times we don't know the mass of the water what do we know instead?

**SUSANNAH:** The volume.

**MARTHA:** The (?).

**TA:** OK, that's true what else? This is the other thing we said earlier.

**SUSANNAH:** The density.

**MARTHA:** We keep saying the thing--the density thing.

**TA:** The density. OK, what is density, what's the definition? What does that mean?

**MARTHA:**  $d$  equals  $M$  over  $V$ .

**SUSANNAH:** It's the mass over volume.

**TA:** Equals what?

**SUSANNAH:** Equals density.

**TA:** OK. So, now if you don't know the mass of the water in the force equation, what else could you put there instead of mass? What's the mass equivalent to?

**MARTHA:**  $V$  times  $d$ .

**TA:** OK.

**SUSANNAH:** OK. Yeah, so we could say it's equal to...

**MARTHA:** Volume times density.

**TA:** OK, so that's what the buoyant force is, if you know the density of the fluid you're in and you know how much volume you are whatever the object is displacing and you always know  $g$ , then you know the buoyant force.

**SUSANNAH:** But, we don't know the volume, we know the density.

**TA:** Well, OK. But, this is just--this is general. But, now let's...so, if we're talking about a pressure that somebody feels it's a force over area so what is the force we're talking about?

**MARTHA:** Buoyant force.

**SUSANNAH:** We're talking about the buoyant force.

**TA:** OK, so let's use that.

**SUSANNAH:** OK.

**MARTHA:**  $dgV$ .

**TA:** OK, now in that equation you have volume and you have area, so if I'm thinking about a room what's--what does volume mean? How do you find the volume of a room?

**MARTHA:** Multiplying by all of them. All the dimensions.

**TA:** What are the dimensions?

**MARTHA:** Twenty by twenty by twenty.

**TA:** But, I mean what are the names?

**SUSANNAH:** The height, the width...

**MARTHA:** The height, width, and length.

**TA:** The height, width, and length. OK, that's how you find volume. What's the area that you have to deal with?

**SUSANNAH:** Oh, length times width.

**TA:** Length times width, ok, so if I have a volume over area (22:12.5) what is that really?

**MARTHA:** That's height.

**SUSANNAH:** Density is equal to--times lengths times width times height...

**MARTHA:** Just the height.

**SUSANNAH:** And, then times gravity over length times width.

**MARTHA:** So, it's just height.

**SUSANNAH:** So, these cancel out.

**TA:** OK, so then what do you end up with?

**MARTHA:** dhg.

**SUSANNAH:** So, now we end up with um d gravity over length.

**MARTHA:** Mass.

**ALICE:** No.

**SUSANNAH:** I mean height.

**MARTHA:** No, you go times h.

**ALICE:** Times h in the top.

**SUSANNAH:** Times h?

**MARTHA:** h is on the top.

**ALICE:** d h.

**SUSANNAH:** Oh, right, right, right.

**TA:** OK.

**SUSANNAH:** So, we can estimate the height.

**TA:** So, to know the pressure somewhere you have to know the density of the stuff. So, we're talking about this dorm room, do you know the density of air?

**MARTHA:** One point.

**TA:** Yes, OK. You know g.

**SUSANNAH:** Uh-huh.

**TA:** OK, and then if you knew the height. So, the question is asking you about a difference in pressure.

**SUSANNAH:** Oh!

**TA:** A change in pressure.

**SUSANNAH:** So, if it's at zero, so we can say for the floor (23:19), the floor pressure...is equal to the density times gravity times (?) maybe?

**TA:** OK.

**SUSANNAH:** And, then the pressure of the ceiling is equal to the density times gravity...

**MARTHA:** Times twenty feet, too.

**SUSANNAH:** Twenty...

**MARTHA:** Oh! Sorry twenty feet.

**TA:** Whatever height you say.

**SUSANNAH:** Twenty feet.

**TA:** OK. Alright, that's fine.

**SUSANNAH:** And, then we just take the difference.

**TA:** What is...sure.

**SUSANNAH:** This minus...

**MARTHA:** And, we do know the density.

**TA:** Alright, let me ask you a slightly different question just to finish all this up and you understand it more than for just this little problem.

**MARTHA:** Right.

**TA:** What if your dorm room is on the fourth floor.

**SUSANNAH:** Oh!

**TA:** So, that the floor is not really at zero.

**SUSANNAH:** So, we have to write an assumption.

**MARTHA:** We have to put a height on that.

**TA:** OK. So, let's say that the fourth floor height is um eighty feet and then the ceiling on the fourth floor is a hundred feet.

**SUSANNAH:** Right.

**MARTHA:** It'd be the same thing as in the first one. It'd be higher, though. It'd be higher, but it would be relatively...

**SUSANNAH:** We'd have an actual pressure for the (24:30) for the floor.

**TA:** Right.

**SUSANNAH:** And, then we have a greater pressure for the ceiling.

**TA:** So, when you do this one and you do that difference, what's the answer going to be?

**SUSANNAH:** Um, it's going to be  $p_C$ .

**TA:** OK, so what is  $p_C$ ? (24:45) It's  $d g$  twenty.

**SUSANNAH:** Yeah.

**TA:** OK, if I had the fourth floor at eighty feet and then the ceiling of it was at a hundred feet and you did the difference what's the answer going to be?

**SUSANNAH:** It's going to be  $p_C$  minus twenty, or something.

**MARTHA:** Wait, you asked if it's--you said it was eighty on the floor, right? And, a hundred on the ceiling?

**TA:** Actually, yeah.

**MARTHA:** So, you're asking...

**SUSANNAH:** Then, we just sub--sub--put eighty here, and a hundred here, because that changes things.

**TA:** OK, so alright, let's erase the zero and twenty for a moment. And, instead of putting numbers at all let's just put height, let's call it  $h_{sub F}$ , for the height of the floor. Then,  $h_{sub C}$  for the height of the ceiling. Now your delta  $p$  equation you wrote, what do you get now for delta  $p$ ?

**MARTHA:**  $h_C$  minus  $h_F$ .

**TA:** Just  $h_C$  minus  $h_F$ ?

**MARTHA:** No,  $d g h_C$  minus  $d g h_F$ .

**SUSANNAH:** Yeah, it's  $h_C$  minus  $h_F$  times  $d g$ .

**MARTHA:** Oh, yeah you can do that, too.

**TA:** Right, OK. So, if you want to know the pressure difference between ceiling and floor you need to know density, gravity, and the difference in the height.

**MARTHA:** OK.

**TA:** So, it doesn't really matter where your room is, if this is zero or this is twenty, it's just what's the difference?

**MARTHA:** It'll be the same amount (?).

**TA:** Same amount of shift, yeah.

**MARTHA:** (?).

**SUSANNAH:** Alright, let's

**MARTHA:** Let me write all that down. (26:38)

**SUSANNAH:** Yeah.

**MARTHA:** So, we have to write assuming--well it doesn't really matter, if we assume if it's on the floor. Oh, wait what did we have before we did h also?

**SUSANNAH:** Hmm?

**MARTHA:** What did we have there before we put h? You just have  $p_F$  and  $p_C$ ? Like in the  $p_F$  equals  $d h h_F$ , what did you have there before?  $p_C$  and  $p_F$ .

**SUSANNAH:** Oh, because what is volume equal to, length times width times height.

**MARTHA:** No, I mean here. What did you--You know you erased what you had before there. What did you have there before?

**SUSANNAH:** Oh, just the numbers.

**MARTHA:** Oh!

**SUSANNAH:** Just numbers.

**ALICE:** So, what are we doing for this? For A, what are we doing?

**MARTHA:** (?)

**ALICE:** (?)

**MARTHA:** So, density equals one point, ah one point kilograms per (?). For floor is zero...

**ALICE:** We have to change feet to meters, right?

**MARTHA:** Yeah.

**SUSANNAH:** Pressure, so...Can I ask you a question, how different is the air pressure at the ceiling in percent. So, are you--you think that the height of a room would be twenty feet?

**ALICE:** See I was thinking it would be--that's too high. I was thinking it would be like 14.

**MARTHA:** Well, if you live on the--

**SUSANNAH:** We should do meters, we should do meters. We should look up meters.

**MARTHA:** Well, you have to convert it to meters. I converted it to meters.

**SUSANNAH:** Well, why don't we just think about meters. Cause you know, we can say a meter stick is about that tall.

**ALICE:** No, it's a little less. It's like three feet.

**MARTHA:** Well, twenty feet--twenty feet is six point five six meters.

**ALICE:** Like three meters.

**MARTHA:** Twenty feet is six point five six meters, that's not--

**SUSANNAH:** That seems like a lot of meters.

**MARTHA:** You think?

**SUSANNAH:** I'm thinking about the height of this room, right?

**ALICE:** Three and a half meters.

**SUSANNAH:** The height of this meter--this room. I'm thinking one, two, three.

**ALICE:** I'm thinking three and a half

**MARTHA:** Three feet, then. Three meters.

**SUSANNAH:** Three meters. Three meters.

**ALICE:** Three and a half, put three and a half.

**MARTHA:** Three point five.

**SUSANNAH:** Three and a half.

[ALICE leaves]

**MARTHA:** So, we need the total weight of air--oh air.

**SUSANNAH:** But, we don't know the mass of it. So, what is mass equal to? Mass is equal to volume times density. We know the density.

**MARTHA:** And, we know the volume.

**SUSANNAH:** And, we know the volume is equal to length times width times height. So, we want to cancel something out.

**MARTHA:** OK, so, OK. Wait. Weight equals  $mg$ .  $m$  is density times volume.

**SUSANNAH:** I think I wrote that wrong.

**MARTHA:** Volume is length (?). So, it'd be--are we saying it's...?

**SUSANNAH:** Hmm?

**MARTHA:** Four meters maybe? No.

**SUSANNAH:** Length of what? We don't need to know the length, because we cancelled it out.

**MARTHA:** But, we need it for the next problem.

**SUSANNAH:** Oh, do we? Oh.

**MARTHA:** Cause it's just weight of the air in the room.

**SUSANNAH:** Oh, OK, wait a minute this is number four. This is A this is B. Um. Estimate the total weight of the air in the room. So, since weight is equal to mass times gravity. And, mass is equal to...

**MARTHA:**  $d$  times  $V$ .

**SUSANNAH:** Mass is equal to volume times density. And, gravity...so then weight is equal to volume times density times gravity. So...

**MARTHA:** We know  $d$ .

**SUSANNAH:** Oh, see, now that we know the pressure, we know what the pressure is, we can go back to another formula and figure out what the volume is, right?

**MARTHA:** Do we really need to?

**SUSANNAH:** I mean we can. It would be easy. Cause it's pressure is equal to the force over the area. Well, the pressure is equal to yeah. Pressure is equal to volume times density times gravity over length times width.

**MARTHA:** Over? Why over?

**SUSANNAH:** Pressure is equal to force over area.

**MARTHA:** Oh.

**SUSANNAH:** So, length times width times height density and gravity.

**MARTHA:** But, we don't really need to find pressure it seems like.

**SUSANNAH:** But, if we know the pressure we can find the volume. See, cause we know that pressure is equal to volume times density times gravity over weight times width.

**MARTHA:** Don't leave us.

**TA:** I have to leave. Someone else will be here soon.

**MARTHA:** Oh, OK.

**SUSANNAH:** I'm hoping. Alright, but I'm thinking that we can just go back to like a simple formula.

**MARTHA:** And, do what.

**SUSANNAH:** And solve for volume.

**MARTHA:** But, isn't that the...

**SUSANNAH:** Because now we know the number of moles we know the temperature, we know the constant and we know the pressure, so all we need to know now is the volume.

**MARTHA:** Oh! I see.

**SUSANNAH:** Because, if we know the volume then we can just multiply it times density and gravity.

**MARTHA:** And, it can be done like that because it's the whole room?

**SUSANNAH:** Right, um.

**MARTHA:** Well, it says here of the room.

**SUSANNAH:** We just want to calculate the volume. It's not going to change whether we're on the ceiling or the floor.

**MARTHA:** Oh, exactly.

**SUSANNAH:** So, we can actually.

**MARTHA:**  $pV$  equals  $nRT$ .

**SUSANNAH:** Yeah, so  $pV$  equals  $nRT$  and the temperature is two seventy three plus thirty seven. Thirty seven is room temperature, right? Celsius?

**MARTHA:** Yeah.

**SUSANNAH:** OK, so then it's three ten Kelvin.

**MARTHA:** Three ten Kelvin. It is thirty seven, isn't it?

**SUSANNAH:** I think so. Volume is equal to  $nRT$  over  $p$ . So, volume is equal to...

**MARTHA:** What's  $n$ ? What's our mass? Our mass is...

**SUSANNAH:** Mass is equal to volume times density. Oh...

**MARTHA:** Where do we get that weight? It's...

**SUSANNAH:** Mass is equal to volume times density, because um because--because we manipulated that formula. Cause density is equal to mass over volume.

**MARTHA:** I didn't put volume in this one.

**SUSANNAH:** Huh?

**MARTHA:** It's  $d$  times  $V$ .

**SUSANNAH:** We don't need to, because we cancelled volume out.

**MARTHA:** Oh. Oh, true. So, it's just h.

**SUSANNAH:** Yeah, so if we know that um see I circled all--all the little things that we should know. So, if we know that mass well we have to convert the mass to moles.

**MARTHA:** Moles.

**SUSANNAH:** But, we need to know the volume first, [expletive deleted] Well, maybe we can cancel something out. Let's write volume as, so volume is equal to length times width times height. Which is equal to length times width times height times density, which is...

**MARTHA:** (?)

**SUSANNAH:** Well, just push d. Yeah times dRT. Over p. So, we can do something with this. 'Cause we know all of these--we know all of these. These are numbers.

**MARTHA:** Like I guess it's just estimating. The volume, that's why I was saying length times width times height. We're going back to one. If we use this. The same thing.

**SUSANNAH:** I feel like he wants us to use what we solved up here down here.

**MARTHA:** Yeah, that's what I'm saying.(36:07)

**SUSANNAH:** Do you think we should just do that using the height that we just estimated? Because the height and the width and the length are not all the same. Unless you have a box for a dorm room. It's a pretty damn big dorm room. No, dorm rooms are tiny. So, if we have this wall and we have the wall falling down, then that would be about the size.

**MARTHA:** I need to see something, actually. OK. OK. So, we know that, did you--oh you didn't erase anything. Good.

**SUSANNAH:** No.

**MARTHA:** So, we're looking for volume, right? No, we're looking for weight. Weight equals mg. And, we know d times g is...

**SUSANNAH:** Oh, is that what is was asking for? The total weight of the air.

**MARTHA:** We know density, right? We know that. Volume equals length times width times height.

**SUSANNAH:** Uh-huh.

**MARTHA:** And, we know the height, we estimated to be three point five meters.

**SUSANNAH:** Uh-huh. Don't put that--don't put the numbers in, because that will confuse us.

**MARTHA:** OK.

**SUSANNAH:** We just--we know that, we know what the variables are. We know that

you have them.

**MARTHA:** OK.

**SUSANNAH:** And, we know that volume is equal to length times width times height. So, just write that over again. But, we know what weight is equal to. Weight is equal to mass times gravity. Right?

**MARTHA:** Yeah, but mass is  $d$  times  $V$ .

**SUSANNAH:** Right. OK. And, we know that volume is equal to length times height times width. So, write  $d$  times  $L$  times  $H$  times  $W$  times  $g$ . Right.

**MARTHA:** I guess, estimate length and width?

**SUSANNAH:** Yeah. That's all we have left to do.

**MARTHA:** Does that seem OK? We don't--I guess. Cause we got this from A.

**SUSANNAH:** She doesn't know what we're doing?

**TA:** I know what you're doing.

**SUSANNAH:** Oh, you do? Oh, OK.

**MARTHA:** Oh, OK.

**SUSANNAH:** (?). Um, well basically we have all these assumptions over here.

**MARTHA:** That's from A.

**SUSANNAH:** Yeah, this is from A. So, what we did was we we, ultimately we calculated the pressure of the room. But, in order to calculate the pressure we need the volume, but we cancelled out the volume. But, we know volume is equal to length times width times height. And, we know that mass is equal to volume times density. Because, density is equal to mass over volume.

**MARTHA:** It's the same thing. We have to use this.

**SUSANNAH:** So, we just need to estimate.

**MARTHA:** Estimate the length and width. Length.

**SUSANNAH:** We can just make the dorm a box. It would make it very easy.

**MARTHA:** Well a dorm is a box. A box basically.

**SUSANNAH:** Write that as our assumption. From personal experience my dorm room was a box.

**MARTHA:** A dorm room is a box.

**SUSANNAH:** Alright.

**MARTHA:** So, what you're saying is three point five three point five three point five.

**SUSANNAH:** Uh-huh, if that's what you think? Wouldn't you say that this is about three point five meters?

**TA:** What do you think? How high--

**SUSANNAH:** Well, cause a meter stick goes about here.

**MARTHA:** I think it goes more, maybe. No, it goes here, that's right.

**SUSANNAH:** Well, it looks bigger.

**TA:** Is your dorm room this tall?

**MARTHA:** If you're on the one in the eighth floor it is.

**SUSANNAH:** Well, we said we were on the ground floor.

**MARTHA:** Oh, ground floor.

**SUSANNAH:** Well, we can say it is. One, two, three.

**TA:** Do you think your dorm room is this tall? This seems luxury for a dorm room

**MARTHA:** Especially, (?) it's going to be luxury.

**SUSANNAH:** We live in a suite.

**MARTHA:** Yes, we have a suite in South Campus, that's why it's so nice.

**TA:** Alright.

**SUSANNAH:** (?) Some really nice (?).

**MARTHA:** Princess...like huge dorms. Um.

**SUSANNAH:** Do you want to just change it to three meters?

**MARTHA:** Or, two point five.

**SUSANNAH:** Two point five.

**MARTHA:** Two point five would be like a little bit higher than that. That actually makes a little sense.

**SUSANNAH:** One two. OK, let's do two point five. That means we have to change our first answer. That's not too bad. That's not too difficult.

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<sup>i</sup> NSF grant REC 008-7519. For details on this project, see

<http://www.physics.umd.edu/perg/role/>.

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<sup>ii</sup> This turns out to be the case with epistemological state measured by pre-post MPEX and conceptual state measured by fractional gains on the FCI. Strong gains were obtained in both measures. These results will be documented elsewhere.

<sup>iii</sup> E. Redish, *Teaching Physics with the Physics Suite* (John Wiley & Sons, Inc., 2003).

<sup>iv</sup> E. Mazur, *Peer Instruction: A User's Manual* (Prentice Hall, 1997).

<sup>v</sup> D. Sokoloff and R. Thornton, *Interactive Lecture Demonstrations in Introductory Physics* (John Wiley and Sons, 2004); D. R. Sokoloff and R. K. Thornton, "Using interactive lecture demonstrations to create an active learning environment," *Phys. Teach.* **35**, 340-347 (1997).

<sup>vi</sup> L. McDermott, P. Shaffer, and the University of Washington Physics Education Group *Tutorials in Introductory Physics*. (Prentice-Hall, Inc., 2002).

<sup>vii</sup> M. Wittmann, R. Steinberg, and E. Redish, *Activity-based Tutorials*, (John Wiley and Sons, Inc., 2004).

<sup>viii</sup> R. Lippmann, *Students' understanding of measurement and uncertainty in the physics laboratory: Social construction, underlying concepts, and quantitative analysis*. PhD dissertation, University of Maryland (2003).

[<http://www.physics.umd.edu/perg/Dissertations/Lippmann>]; R. Lippmann-Kung,

"Teaching the concepts of measurement: One example of a concept-based laboratory course," *Am. J. Phys.* **73**, 771-777 (2005).