



## **On Adopting an Inquiry Stance: A Case Study of Three Teachers as They Integrated the InterLACE Technology to Encourage Student Sharing and Reasoning**

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# **On Adopting an Inquiry Stance: A Case Study of Three Teachers as They Integrated InterLACE Technology to Encourage Student Sharing and Reasoning**

## Abstract

To produce a more technically and scientifically literate population, we need to place student ideas at the forefront of science and engineering classroom activity so that those ideas can be exposed and refined and the students feel they have a stake in building that knowledge base. Accordingly the Interactive Learning and Collaboration Environment (InterLACE) Project has created a technological tool that allows students to post their thoughts via a Web-based platform to a centrally located screen for subsequent discussion and collaborative attainment of a deeper understanding. This paper examines in-class-use cases involving three teachers of diverse backgrounds who participated in our project; the goal of which is to answer the following questions: 1) How did our tool change the way the way the teacher engages with student thinking? 2) How did our technology support the teacher as he interacted with student ideas? 3) What are the factors that enable the teacher to or prevent him from capitalizing on opportunities afforded by the tool to probe student reasoning? 4) How does this engagement, as well as other aspects, affect the student discussions that result from using the tool? In so doing, we hope to inform future improvements made to the tool and to add to the collective understanding of teacher interaction with student thinking and the classroom discussions resulting from that process.

## Introduction

The approach to science, technology, engineering, and mathematics (STEM) education has experienced a philosophical shift away from the memorization of facts, figures, and procedures toward one in which students engage in authentic practices (i.e., of scientists or engineers) as they explore and digest STEM content. This shift provides the basis for one of the cornerstones of the framework of the Next Generation Science Standards<sup>2</sup> proposed by the National Research Council of the National Academy of Sciences: The first of the framework's three dimensions emphasizes the need to introduce scientific and engineering practice in K–12 science education to help students “understand how scientific knowledge develops and [to give] them an appreciation of the wide range of approaches that are used to investigate, model, and explain the world.” Central to this practice-and-process focus is encouraging students to share their ideas, and the reasoning behind them, and work together to build deeper understandings of scientific phenomenon and their applications. By eliciting students' knowledge of science garnered from experiences both inside and outside the classroom, teachers can empower students to make sense of the world around them by refining the ideas they already possess through a dynamic process of argumentation, experimentation, and theory building, thereby constructing robust scientific comprehension. Furthermore, through design-based or engineering activities, students can devise experiments or artifacts that test or leverage their scientific understanding in the sorts of authentic ways professional scientists and engineers do. However, in the classroom context, interacting with the often-divergent ideas of 20 or more students while employing an unfamiliar or little-used design-based pedagogy might seem an overwhelming and unproductive task. This mission might appear even more impossible given the current climate, which necessitates the

coverage of a great breadth of content in a relatively short amount of time to meet the demands of standardized tests. It is our goal with the Interactive Learning and Collaboration Environment (InterLACE ) Project to support teachers and students in this pursuit through Web-based tools that elicit and document the aforementioned process of design-based inquiry.

## Background

### *Focus on Students' Reasoning*

Taking the constructivist perspective that students use and develop existing resources to construct knowledge with their peers and teachers<sup>15,16,20,22</sup>, we posit that any science learning begins with students' ideas as the initial building block. Recent reform and research-and-development projects in science and engineering education have emphasized the importance of science argumentation or science talk<sup>1</sup> to expose students' ideas and engage students in making sense of those ideas in the pursuit of developing a robust understanding of the world around them. These projects have involved working with teachers through professional development and/or curricular interventions that promote classroom discourse in which teachers elicit students' ideas and then facilitate conversations that encourage students to reason about, critique, build upon, and then test and evaluate those ideas.

Research shows that this sort of approach exhibits impressive gains in students' comprehension of and beliefs about science. Focusing on students' ideas, as well as subsequently discussing those ideas in the classroom, has also been shown to more effectively reach a greater range of learners<sup>5,22</sup>. Many of these teaching interventions and attempts to reform curriculum aim to create rich classroom discussions in which teachers concentrate on facilitating scientific conversation rather than providing correct answers<sup>6,13</sup>. Successful examples of these sorts of interactions often describe provocative debates; however, for the most part, these debates engage just a small number of students' ideas. Of course, getting full responses from every student and steering the students away from simply agreeing with those whom they may feel already know the "right" answer would be quite time-consuming. For this reason, we believe a more inclusive approach that engages all students' ideas as they work toward shared scientific meanings is called for.

### *Implementing Technology-Centered Pedagogy*

Reforming science education to focus more on the practices and processes of science (e.g., science argumentation and design-based science) is a daunting task; and, as such, groups have explored how technology can support teachers and students in the pursuit of science<sup>9,10,17</sup>. The WISE and Knowledge Forum platforms<sup>9,17</sup> provide environments in which students can build and connect concepts as they develop their scientific understanding. These tools have seen success; however, the success has been heavily reliant on the effective implementation of the tool by the teachers. Professional development must accompany any technological tool to support educators in recognizing its myriad affordances and how to engage students in the environment it creates.

## *InterLACE Project and the Thought Cloud*

In line with this call for the exposure of student reasoning to enhance conceptual gains, the InterLACE Project started to develop the Thought Cloud in the winter of 2011. The project was established earlier that year with the aim to create Web-based technologies that promote collaborative design-based inquiry instruction in high school science and engineering classrooms, relying mainly on the input of our Design Team, composed of six teachers located in Massachusetts and New Hampshire. Starting in the fall of 2011, we conducted monthly Design Team meetings and in-class observations of our teachers' classrooms to determine their needs and concerns as we supported them in implementing design-based inquiry projects. In light of the information we gathered from these meetings and observations, we developed the following design principles:

- Facilitate student discussion with the aim to empower students to share, develop, and build ideas, theories, and designs collectively.
- Promote collaboration among individual students, student groups, and teachers.
- Enable the teacher to act as a facilitator of the above two principles, as well as to allow them to focus on student thinking.

Accordingly, we decided that our first tool, the Thought Cloud, should make students' reasoning visible to their teacher as well as their fellow classmates. The tool allows teachers to create a lesson plan on InterLACE's Web site consisting of questions and challenges, which they can then present to their students on a centrally located screen in the classroom as well as through the desktop, laptop, or tablet devices the students use to answer those questions and challenges. The tool then aggregates the students' posts, which the teacher and students can view and subsequently discuss. The first version of the tool was barebones and allowed text-only posts that could be rearranged onscreen so that the teacher and the students could group responses by patterns such as similarity (for examples of this, see "Kraig's Use of the Thought Cloud," below). A second version of the tool introduced the ability to comment on, highlight, and compare posts, and subsequent versions permitted and improved upon the ability to upload photos and sketches.

## Methods

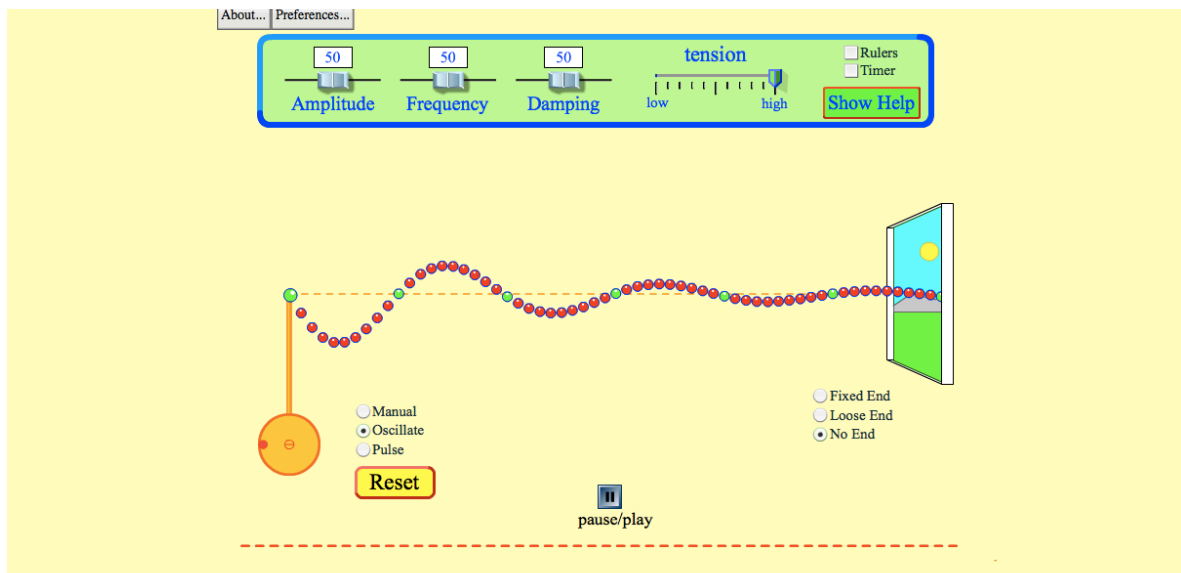
The assemblage of our Design Team was an informal process. We asked physics high school teachers who were known to us through previous interactions with the Tufts University Center for Engineering Education and Outreach to participate in the design and implementation of Internet-based tools that promote collaborative design-based inquiry instruction. We were able to put together a diverse group of teachers in terms of the years of experience they possess and the socioeconomic and ethnic makeup of the student populations they teach. The three teachers we focus on in this case study are similarly distinct: Kraig has six years of experience and works at a large high school in suburban Boston with a student population that is mainly black, Hispanic, and low income. Charles has 16 years of experience and works at a mid-size rural high school in New Hampshire, in a community that is predominantly white and middle income. Sam was a first-year teacher at the time of our study, covering for Design Team leader Greg as he took his sabbatical, and was working at a small Boston private school, which offers tuition assistance to more than a third of its students, who are mostly white.

The data we are about to present is drawn from videotaped observations of in-class use of our tool during initial and subsequent testing in the spring of 2012, and our analysis is additionally based on interviews conducted in the summer of 2012 and in-class observations we conducted before the Thought Cloud's rollout. This analysis is guided by the following questions: 1) How did our tool change the way the way the teacher engages with student thinking? 2) How did our technology support the teacher as he interacted with student ideas? 3) What are the factors that enable the teacher to or prevent him from capitalizing on opportunities afforded by the tool to probe student reasoning? 4) How does this engagement, as well as other aspects, affect the student discussions that result from using the tool?

### Kraig's Use of the Thought Cloud

In mid-March 2012, Kraig tested version 1 of the Thought Cloud in his classroom for the first time. During the weeks leading up to this debut, two researchers from our group assisted Kraig in designing lesson plans, crafting questions, and uploading them to the Thought Cloud for his students to answer and then discuss over the course of a single class period. He planned to use the tool for three of his physics classes: conceptual, college-prep, and honors.

At the time, Kraig's conceptual and college-prep classes were covering the concept of waves, so he crafted a lesson plan consisting of six questions based on the Waves on a String PhET simulation (see figure 1; you can also go to <http://phet.colorado.edu/en/simulation/wave-on-a-string> to run the simulation yourself), which allows users to create waves along a beaded string and change the amplitude and frequency of the wave and damping and tension in the string; an animated re-creation of air molecules traveling in a sound wave; and a clip from the Discovery Channel's *The Universe* series that featured an astronaut on Mars whose space suit is ripped open when he is caught in a dust storm. The purpose of the simulation, upon which the first two of the six questions were anchored, was to give the students a chance to observe and interact with the motion and characteristics of transverse waves. The sound wave animation served to help students visualize a sound wave on a subatomic level. And the aim of *The Universe* clip was to prompt the students to think about what sound waves need to propagate and how that differentiates them from light waves.



**Figure 1: PhET’s Waves on a String simulation.**

During the first class on the day of the Thought Cloud’s debut with his conceptual students, Kraig acclimated himself to the tool. After having his students respond to the questions and prompts within the Thought Cloud during class, Kraig then began to interact with the responses, which were projected on the SMART™ board at the front of the room. Initially he read the students’ answers aloud, evaluating the responses, grouping them onscreen by similarity, and eliciting the students’ opinions by asking, “What do you think?” Resulting conversation was sparse. A contributing factor to the lack of discussion might have been class size: Six students were in attendance, a headcount that matched the number of laptops we brought into the classroom, thus students worked on their answers individually rather than collaboratively. Additionally, a fire drill occurred during the class, truncating and interrupting the flow of the lesson plan. Before the fire drill, the class was able to complete the first two questions, based on the PhET simulation (see figure 1): “Compare the motion of the wave crests to that of the green beads. Which way are they moving? Are they vibrating or traveling?” and “Why is this a transverse wave?” After the fire drill, Kraig skipped to the last two questions, based on *The Universe* clip. Upon showing the video, Kraig directed his students to answer question five: “Normally the commander can speak to the other crew members through a microphone in his spacesuit. But if a rip in the suit causes the air to leave the suit quickly and he tried to speak into the microphone, would his crewmates hear him? Why or why not?”

The students’ responses within the Thought Cloud were split evenly between the ideas that the commander could not speak because he lacked air to breathe and that sound waves need air to propagate, so even if the commander could speak, there would be no medium to carry the sound of his voice. After reviewing the answers, Kraig identified this division while reading the answers aloud, grouped them accordingly, and then attempted to stoke a debate:

1. **Kraig:** “So what do you guys think?”
2. **Unidentified student:** “Makes sense.”

3. **Kraig:** “Yeah. I mean, first of all, these three make sense: Like, if you’re dead, you can’t talk, okay? But let’s just think about this. Before you die, why can’t you speak? Again, just reiterate, why can’t you speak if there’s no air before you’re dead?”
4. **Unidentified student:** “Because sound waves need air to travel.”
5. **Kraig:** “Okay.”
6. **S:** “There’s no medium.”
7. **Kraig:** “There’s no medium. Good.”

To get the students to engage with their classmates’ responses and thus spur conversation, when they had posted their answers to question six—“The commander could shine a flashlight at crew members and definitely get their attention. What does this tell you about the difference between light waves and sound waves?”—Kraig asked them to pick an answer they agreed with or was similar to theirs and read it aloud. Unfortunately, little palpable discussion among the students resulted.

Kraig attempted to enact the same lesson plan with his college-prep students, his third class that day, but it, too, was interrupted, this time by a failure in the school’s Internet connection as the students were answering question four, based on the animation of air molecules traveling in a sound wave: “Sally says this wave is longitudinal and electromagnetic. Describe why you agree or disagree with her.” Unable to view the students’ answers, Kraig bypassed discussion of that question but decided to proceed with an improvised take on the original lesson plan, thus providing us with a window on the instructional stance Kraig takes without the tool. When he realized he could not show the students *The Universe* clip because he hadn’t fully downloaded it from the Internet, he described it to them:

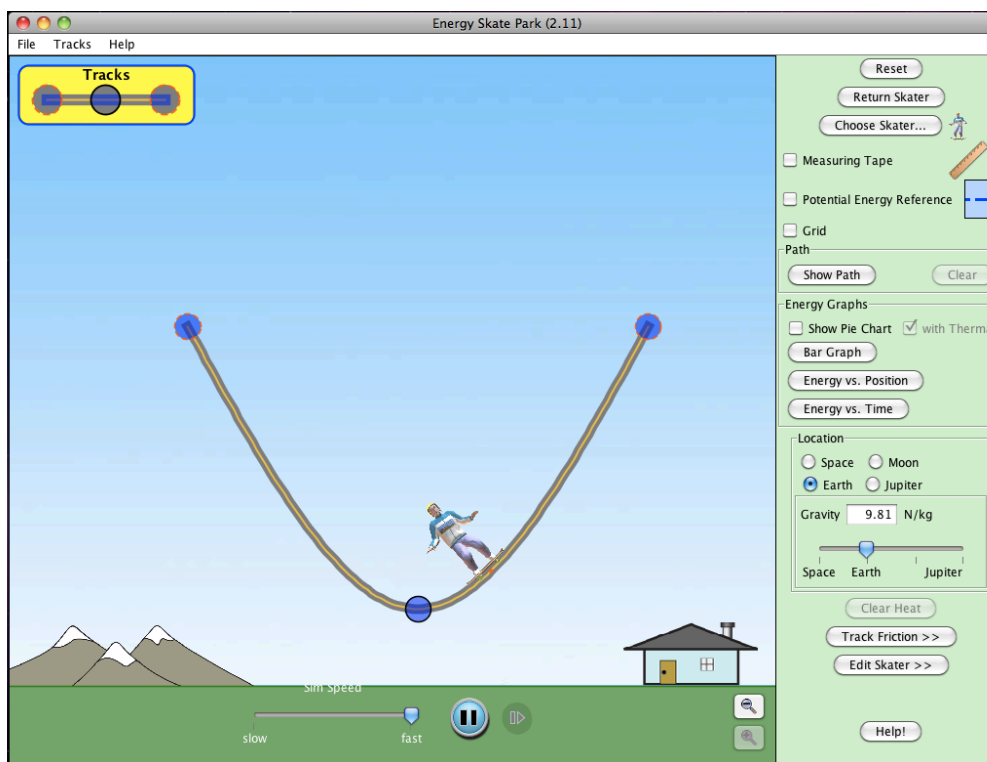
8. **Kraig:** “So I’ll tell you what was in that video. [*Students murmur.*] It’s about Mars.”
9. **Unidentified student:** “Really?”
10. **Unidentified student:** [*Inaudible.*]
11. **Kraig:** “Yeah, they’re saying astronauts go to Mars.”
12. **Unidentified student:** “That’s so cool, dude [*inaudible.*]”
13. **Kraig:** “And—”
14. **Unidentified student:** [*Inaudible.*]
15. **Kraig:** “Yeah. You know on the beach—they didn’t find that—you know on the beach they’ve got, they’ve got sand, right?”
16. **Unidentified student:** “Yeah.”
17. **Kraig:** “Okay? And the sand is pretty smooth. Why do you think the sand gets smooth? It has to do with—”
18. **Unidentified student:** “It has to do with something about waves.”
19. **Kraig:** “The waves. The waves break and come back, etc.... Now, so waves break and they kind of get the sand all smooth. Okay? But on Mars the sand is really like rough and sharp, like razor blades.”
20. **Unidentified student:** “Uh-oh.”
21. **Kraig:** “So think about this: You go to Mars, the wind starts blowing, what happens to your spacesuit?”

22. **Unidentified student:** [*Inaudible.*]
23. **Unidentified student:** “Nothing, right?”
24. **Unidentified student:** “Nothing?”
25. **Unidentified student:** “The suit gets ripped open.”
26. **Kraig:** “Why?”
27. **Unidentified student:** “Because you said it’s sharp.”
28. **Kraig:** “What’s sharp?”
29. **Unidentified student:** “The sand.”
30. **Kraig:** “That’s right. Now the spacesuit gets ripped open, what happens then?”
31. **Unidentified student:** “You can’t breathe.”
32. **Unidentified student:** “All the air comes out.”
33. **Kraig:** “All the air comes out. Now you try to yell for help—”
34. **Unidentified student:** “No one’s there.”
35. **Kraig:** “Why can’t people hear you?”
36. **Unidentified student:** “No one’s there.”
37. **Unidentified student:** “Because there’s no air.”
38. **Unidentified student:** “No air.”
39. **Unidentified student:** “You can’t breathe.”
40. **Kraig:** “Because there’s no air. Why would you need air?”
41. **Unidentified student:** “To speak.”
42. **Unidentified student:** “To hear.”
43. **Kraig:** “Why do you need air to talk?”
44. **Q:** [*Inaudible.*]
45. **Kraig:** “What’s that, Q?”
46. **Q:** “It transports a voice.”
47. **Kraig:** “Because it transports a voice. Sure. Okay, how?”
48. **Q:** “Sounds...”
49. **Unidentified student:** “Through the air.”
50. **Kraig:** “Right, sound waves through the air. That’s right.”

Additional examples from Kraig’s second class on the day of the Thought Cloud’s rollout—his honors class—provide further contrast between the instructional approaches he took with and without the tool. His honors class was covering the work-energy theorem at the time, so Kraig put together five questions built around the Energy Skate Park PhET simulation (see figure 2; also, <http://phet.colorado.edu/en/simulation/energy-skate-park>). In it, skaters of varying weight—a ladybug, a bulldog, a person—can be placed on a half pipe and set in motion. Users can view the changes in potential, kinetic, and thermal energy by turning on a bar graph, choose whether the skater is on Earth, the Moon, Jupiter, or outer space, and add or take away friction. Throughout the first 30 minutes of the lesson, when Kraig’s students observed the simulation, it featured the skater frictionlessly gliding along the ramp so that the students could focus on an idealized situation in which they could tease out the forces acting on the system and the changes in potential and kinetic energy, answering questions such as “Does the normal force do work on the system? Why or why not?” By the third question, a real-world layer was applied, as the students were asked, “Does it seem realistic that the skater would return to the same starting point every time?” followed up by the questions “What forces act on the skateboarder, and are



they changing the energy of the system?” and “If you introduced friction to the system, how would that change its total energy? Would it be conserved?”



**Figure 2: PhET’s Energy Skate Park simulation.**

Unlike the students in the conceptual class, the honors students had to share laptops in groups of two or three, thus necessitating small-group collaboration. More comfortable with the tool than he had been with his first class, Kraig delegated the task of reading the responses aloud to the students, either by having them read their own answers or ones with which they agreed or disagreed, giving reasons why they supported or rejected the answer. After a majority of the students had answered question two (“Describe how the potential, kinetic, and total energy [PE, KE, and TE, respectively] in the system is changing as the skater rides from one end of the half pipe to the other”; see figure 3), he asked a member of Group D to read its answer aloud: “The total energy is the same because PE and KE are inversely proportional to each other. When PE increases, KE decreases, and vice versa. Therefore TE is always the same. For example, if TE equals 10 Joules, KE plus PE equals 10 Joules at any given point on the ramp.”

Describe how the potential, kinetic and total energy in this system is changing as the skater rides of the half pipe to the other.	
<p><b>Group B</b></p> <p>Potential Energy: At the top of the half pipe on either end, the skater has the most potential energy and the lowest kinetic energy (i.e. 500j of PE and 0j of KE). Kinetic Energy: The skater will have the most kinetic energy at the bottom of the half pipe, and the lowest potential energy (i.e. 500j of KE and 0j of PE) Total Energy: as the skater goes down the sides of the half pipe, potential energy is transferred to kinetic energy; as he goes back up the half pipe, his kinetic energy is transferred to potential energy.</p> <hr/> <p>The Skater begins his descent with high potential energy, which is then transformed into Kinetic Energy as he reaches the bottom of the ramp. His total energy stays the same as no outside forces are acting upon the system. His potential energy decreases as height decreases. His kinetic energy increases as velocity increases. =)</p> <hr/> <p>When the skater is at the ends of the half pipe there's potential energy, and kinetic energy is zero. As he gets closer to the middle of the half pipe there is no potential energy and there is kinetic energy. The total energy in the system is conserved because the potential and kinetic energy are transferred.</p>	<p><b>Group D</b></p> <p>The total energy is the same because the PE and KE are inversely proportional to each other. When PE increases KE decreases, and vice versa. Therefore TE is always the same. For example, if the TE=10J, KE+PE=10J at any given point on the ramp</p> <hr/> <p><b>Group F</b></p> <p>At first, the kinetic energy is 0 (at first meaning when the skater is about to ride down the half pipe). The potential energy is at a high number though. As the skater skates down the ramp, the potential energy starts to decrease and the kinetic energy begins to increase. By the time the skater reaches the bottom of the ramp, the kinetic energy and the potential energy is the same number. Once the skater begins to skate back up the ramp, the potential energy continues to decrease and the kinetic energy continues to increase. So the potential energy is 0 at the other side of the ramp and the kinetic energy is at a high number.</p> <hr/> <p>The potential energy is changing because he's constantly moving, the kinetic energy is changing because of the ramp that is going down and then back up. Total energy is transformed from PE to KE, so energy stays the same</p>

**Figure 3: The honors students' answers to question two.**

Kraig surveyed the students as to whether they agreed or disagreed with Group D's answer. Greeted with murmuring, he quickly elected to let the answer stand without further analysis and then asked Group F to read their answer, leading to the following exchange:

51. **A:** "At first the kinetic energy is zero—at first meaning when the skater is about to ride down the half pipe. The potential energy is at a high number. As the skater skates down the ramp, the potential energy starts to decrease and the kinetic energy begins to increase. By the time the skater reaches the bottom of the ramp, the kinetic energy and the potential energy is the same number. Once the skater begins to skate back up the ramp, the potential energy continues to decrease and the kinetic energy continues to increase. So the potential energy is zero at the other side of the ramp, and the kinetic energy is a high number."
52. **Kraig:** "Okay, so can we just say what that means here? First, the kinetic energy is zero. Let's sketch this out here. [*Starts to sketch on the whiteboard adjacent to the SMART™ board on which the students' posts to the Thought Cloud are projected; see figure 4.*] Okay. So it sounds like KE equals zero right there. But the same, okay. Now potential energy is at a high number, so PE is high [*writes PE=high at the top right corner of the half pipe he has drawn on the whiteboard, then points at the SMART board*]. Next up: Um, as the skater goes down the ramp, the potential energy starts to decrease, and kinetic increases. By the time the skater

reaches the bottom of the ramp, the KE and the PE is the same. Okay. So down here KE equals PE [*writes KE=PE at the bottom of the half pipe on the whiteboard*]. Okay? And as we go down here, we say—this says that the PE decreases [*writes PE decreases near the middle of the half pipe on the right side*]. Is that what it says?”

53. **Unidentified student:** “Yeah.”

54. **Kraig:** “And the KE increases [*writes KE increases just below PE decreases*]. Is that correct?”

55. **Unidentified student:** “Yup.”

56. **Kraig:** “That’s what it says. Alright. Now once the skater begins to skate back up, the potential energy continues to decrease, and the kinetic energy continues to increase. So PE is zero at the other side, and the kinetic energy is at a high number. Okay, so now this one says that PE still decreases [*writes PE decreases near the middle of the half pipe on the left side*], and it says that KE still increases [*writes KE increases just below PE decreases*]. And then this says that PE here equals zero [*writes PE=0 at the top left corner of the half pipe*], and the KE, the KE is high [*writes KE=high just above PE=0, then encircles the entire half pipe*]. Okay? So...that’s...other...yeah...We’ve got slightly...Let’s see. Do these two say the same thing or not? [*Points at Group D’s and F’s contribution on the SMART board.*]”

57. **Unidentified student:** “Basically.”

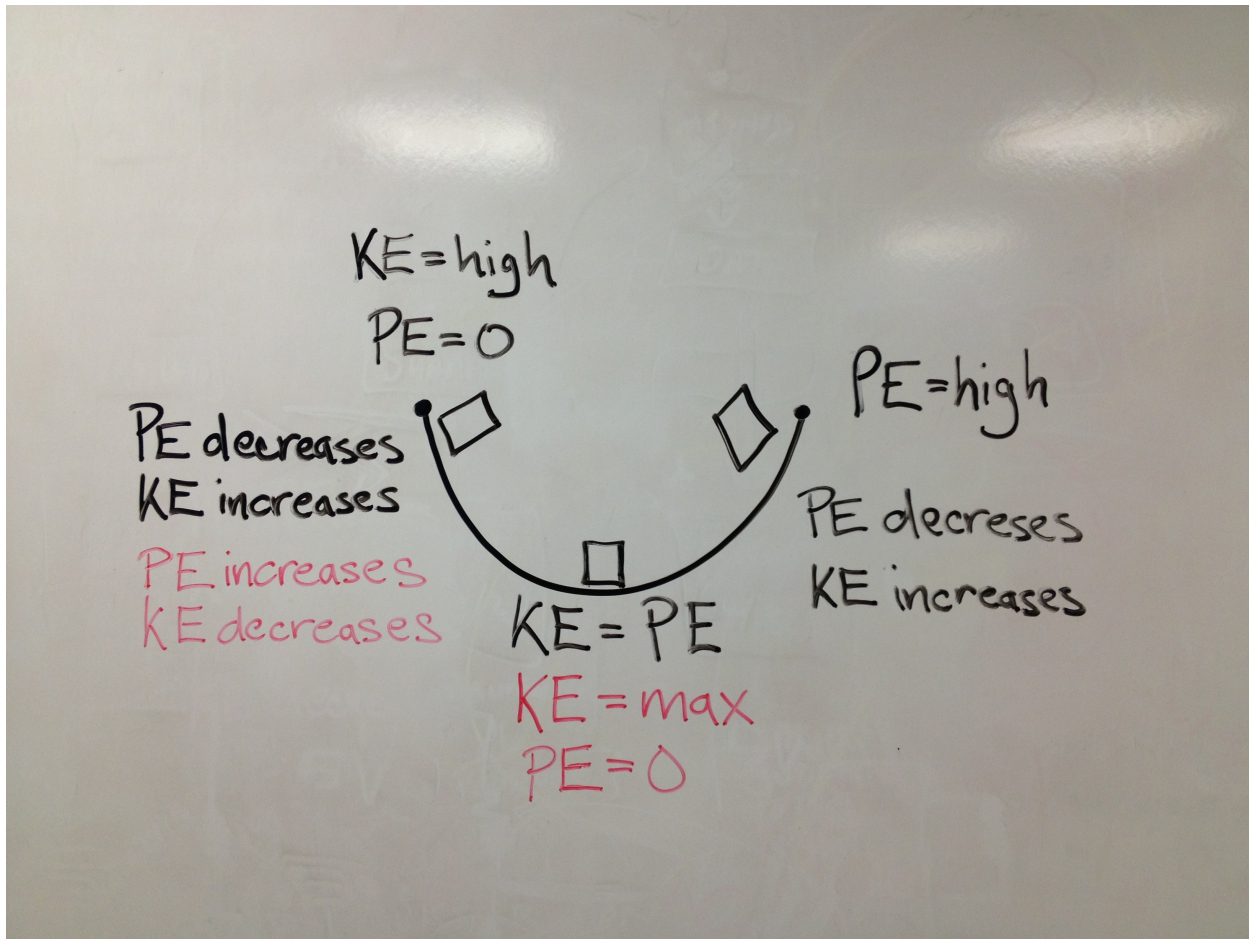
Seemingly, Group D’s answer was obtuse enough to be misconstrued as nearly the same as Group F’s—as evidenced by the student’s response of “Basically” to Kraig’s question as to whether the two said the same thing. So Kraig moved on to Group B, whose answer provided a better contrast:

58. **B:** “Potential energy: At the top of the half pipe on either end, the skater had the most potential energy and the lowest kinetic energy. For example, 500 Joules of PE and 0 Joules of KE. Kinetic energy: The skater will have the most kinetic energy at the bottom of the half pipe and the lowest potential energy. For example, 500 Joules of KE and 0 Joules of PE. Total energy: As the skater goes down the sides of the half pipe, potential energy is transferred to kinetic energy; as he goes back up the half pipe, his kinetic energy is transferred to potential energy.”

59. **Kraig:** “Okay. So let me see if I can get this all right here [*points at SMART board*]. Um, so ‘i.e. 500 Joules...0 Joules of KE...at the bottom of the half pipe...the lowest potential energy.’ Okay, so before [Group F] said that they’re equal down here [*points at whiteboard, underlining with his finger KE=PE at the bottom of the half pipe*]. Does this one say that they’re equal at the bottom? [*Points to SMART board.*] No, what does it say? It says KE is what? Max, right? [*Writes KE=max just below KE=PE.*] KE is at the max. And then the PE is what?”

60. **Students:** “Zero.”

61. **Kraig:** “Zero. [*Writes PE=0 below KE=max.*] Okay? So [Group B] said that. Now ‘as the skater goes down the sides of the—blah, blah, blah—as he goes back up, his kinetic energy is transferred to potential.’ Okay, so [Group B] says as the person goes up, [Group B] said that PE is going to increase and that the KE will decrease. [*Writes PE increases and KE decreases on the left side of the half pipe in the middle.*] So [Group B] said the opposite. I think they're the same up here [*points at top of the half pipe*], but this, they said the opposite up here [*points at bottom and left side of half pipe*]. One group said PE decreases as they go up; the other says PE will increase. Okay, so that’s a conflict we’ve got to work out.”



**Figure 4: A re-creation of Kraig’s sketch of Group F and Group B’s answers. Group F’s contribution is written in black; Group B’s, red.**

Kraig then had the remaining groups read their answers, most of which supported Group B’s. Kraig turned to the simulation to provide the definitive answer: After the representative of the last group read its contribution, Kraig directed the students’ attention back to the simulation and

clicked on the energy bar graph pop-up window, which tracks in real time how the skater's potential, kinetic, and total energy changes as the skater moves up and down the half pipe.

62. **Kraig:** "Okay, now, let's resolve this point going up here. [*Points at half pipe on whiteboard.*] So some people say the PE decreases as you go up; other ones say the PE increases. Let's check it out. So PE is at, what is it down here? [*Points at SMART board, which now shows the PhET simulation; underlines PE on the bar graph at the right of the simulation, which has been paused with the skater at the bottom of the half pipe.*]"
63. **Unidentified student:** "Nega—"
64. **Unidentified student:** "Zero."
65. **Kraig:** "Oh, yeah, it's slightly negative. But first of all the question is, is PE going to increase or decrease? [*Reactivates the PhET simulation, then pauses it when the skater reaches the top of the half pipe.*] What happens as you go up?"
66. **Unidentified student:** "Increases."
67. **Unidentified student:** "It increases."
68. **Kraig:** "Alright? How come? Why? What does PE depend on?"
69. **Unidentified student:** "Height."
70. **Kraig:** "Height. What's happening to your height?"
71. **Unidentified student:** "It's increasing."
72. **Students:** "Increasing."
73. **Kraig:** "Okay. Great. Nice work on that one. That was a complicated one. You did well."

Much like with his conceptual group, Kraig attempted to elicit student opinion with prompts like "What do you guys think about that?" And the students often responded with murmuring. However, after the students posted their answers to question three—"Does it seem realistic that the skater would return to the same starting point every time? Why or why not?"—Kraig asked them to pick an answer other than their own with which they agreed or disagreed, and an actual discussion started to bloom among the students.

74. **Unidentified student:** "Ah, I'll read, um, F's: 'No, it's not. The mass is the same every time, but the velocity isn't going to be the same every single time he moves up and down the ramp.'"
75. **Kraig:** "Okay. Alright. Now, do you agree with that, disagree, what do you, why do you think that's true or not true?"
76. **Unidentified student:** "Uh, well, I think the answer is no."
77. **Kraig:** "Um-hm."
78. **Unidentified student:** "Because, yeah, the mass of the skater [*inaudible*] but the velocity is going to change."
79. **Kraig:** "Okay."
80. **Unidentified student:** "So essentially [*inaudible*]."
81. **Kraig:** "Okay. Alright. So then I would sort of ask why is that velocity going to change? Why is that—?"

82. **Unidentified student:** “I mean, like, realistically, it’s not going to be the same exact velocity every time you go up and down.”
83. **Kraig:** “So when you reach the middle, at the middle will it be the same time every time he’s at the bottom?”
84. **Unidentified student:** “Yeah, I guess.”
85. **Unidentified student:** “It would be zero.”
86. **Kraig:** “Yeah?”
87. **Unidentified student:** “At the bottom, yeah. I mean, I don’t know.”
88. **Kraig:** “You don’t know? Alright.”
89. **Unidentified student:** “Realistically, like, you’re not going to have the same exact velocity every time.”
90. **Kraig:** “Okay, and why do you think maybe not?”
91. **Unidentified student:** “I don’t know why not. He might push a little harder one time—”
92. **Kraig:** “Uh-huh.”
93. **Unidentified student:** “He might kinda stand still on it another time.”
94. **Kraig:** “Okay, what’s he pushing on?”
95. **Unidentified student:** “On the skateboard.”
96. **Student:** [*Inaudible.*]
97. **Kraig:** “Wow, harsh. Okay, someone else, read for us one of these answers.”

### Discussion of Kraig’s Case

Without the tool, Kraig took an initiation, response, evaluation (IRE) approach<sup>12,19</sup> with his students (responses 8 to 50), cherry-picking the ideas that he was looking for and letting the others remain unaddressed. We witnessed Kraig assume the same IRE stance during previous observations in his classroom in the fall of 2011. With the tool, Kraig would lapse into an IRE stance on occasion (response 59: “It says KE is what? Max, right?”; responses 68 to 72: “What does PE depend on?” “Height.” “What’s happening to your height?” “It’s increasing.” “Okay. Great.”), but he also interacted with ideas he might have otherwise ignored in promising ways: He deconstructed them (responses 52, 56, and 61), at one point fully engaging himself in Group F’s answer in the hope that the students would detect the flaw in its answer when comparing it to Group D’s, and refrained from authoritative evaluation (particularly the end of response 56: “So...that’s...other...yeah.... We’ve got slightly.... Let’s see. Do these two say the same thing or not?”). This contrast of Kraig with and without the tool permits us to appreciate a virtue of the Thought Cloud: When voiced in the course of a typical classroom discussion, students’ ideas can be ephemeral and nearly invisible, disappearing moments after they are spoken; when posted to a technological artifact, their ideas can become timeless and concrete, more easily identifiable and assessable, even long after they have been written. We also find it encouraging that a conversation occurred after the students had answered question three (responses 72 to 97): Although it was brief and inconclusive, it was impressive in light of the fact that it was the first day the students had used the Thought Cloud and that both parties comprising the classroom culture were unaccustomed and perhaps uneasy with substantial discussion of physics concepts.



## Charles' Use of the Thought Cloud

The second time Charles used version 1 of the tool with his students, in late February, he prepared a total of 12 questions, eight of which the students completed in class in groups of two, based on the topic of velocity and acceleration and in part on the Moving Man PhET simulation (see figure 5; also, <http://phet.colorado.edu/en/simulation/moving-man>), in which one can adjust the position, velocity, and/or acceleration of a man at the top of the screen, thus gaining an appreciation of how those variables affect his position and motion and viewing the kinds of position, velocity, and acceleration graphs that result from such adjustments. After answering the second question—“If you toss a ball up, what is its acceleration at the top of its path?”—a lively debate ensued when Charles asked T to elucidate her and her partner's answer. While a majority of the groups concurred that the acceleration at the top of the path would be equal to acceleration due to gravity, T's group and another one said it would be zero. T explained that she believed if the ball were going upward, it would need a positive acceleration to do so. Several students chimed in to address T's quandary or to express their own confusion. M stepped in to provide some clarity:

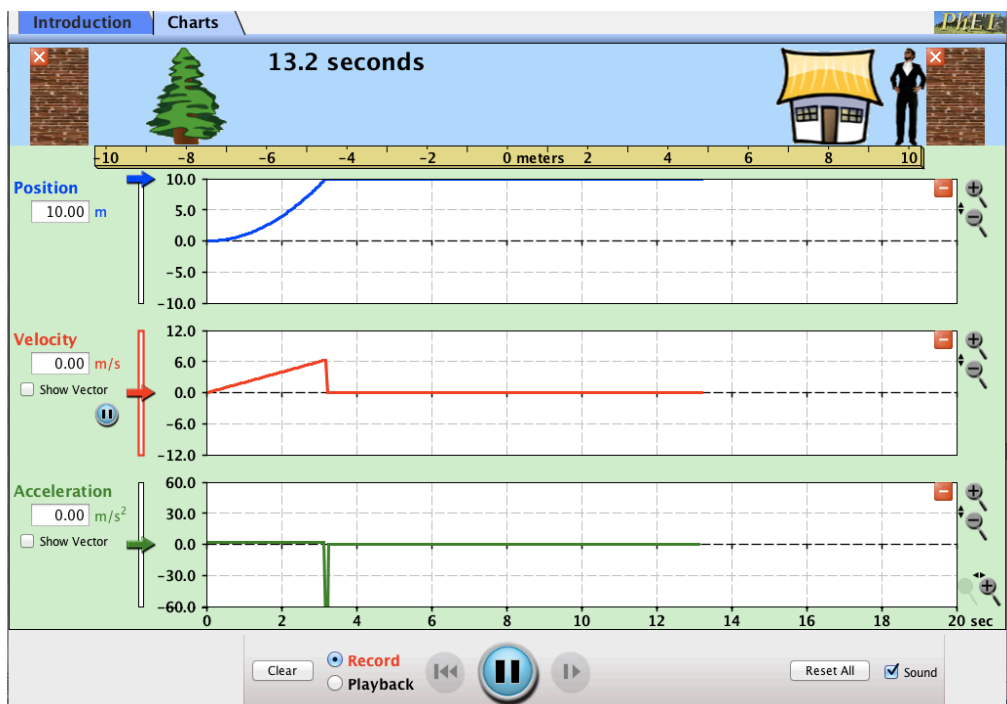
1. **M:** “You guys are getting velocity confused with acceleration. Just because it's going up doesn't mean it has a positive acceleration. It means that that's, like, how fast it's going, and acceleration is what changes velocity.”
2. **Unidentified student:** “Right, but if you're just holding it there, does it have a positive or negative acceleration?”
3. **Unidentified student:** “At no point is there a positive acceleration because the negative acceleration [*inaudible; students talking over one another*].”
4. **Unidentified student:** “[*Inaudible.*] There's an acceleration when it goes like this [*moves fist upward*], but as soon as he lets go, it decelerates.”
5. **Charles:** “So let's—”
6. **M:** “Velocity changes compared to what, like...velocity changes because of acceleration. It doesn't go, like, the other way around.”
7. **Charles:** “So let's—so we're throwing lots of ideas in at once. Let's start to test some. So the, um...so how do I simulate in this case here—”
8. **M:** “Can I try something really quick?”

Charles permitted M to go up to the board, and M proceeded to manipulate the controls of the Moving Man simulation: First, he set the acceleration to  $2 \text{ m/s}^2$  and the velocity to  $0 \text{ m/s}$ , then he put the acceleration at  $0 \text{ m/s}^2$  and the velocity to  $2 \text{ m/s}$ . Charles asked M if he had anything else to add:

9. **M:** “I just wanted to show that it doesn't have to have a positive acceleration to be going. Like, if I only have a velocity, like nothing happens to the acceleration.”

10. **Unidentified student:** “Right, but something would have to have put it into that, to make it start at that velocity.”
11. **Unidentified student:** “Yeah.”
12. **M:** “No, it doesn’t have acceleration.”
13. **Unidentified student:** “But—”
14. **M:** “Acceleration is what changes velocity; velocity does not change acceleration. If I have acceleration [*inaudible; students talking over one another*]. If I have literally, if I have literally zero acceleration or zero velocity and I put the acceleration at two, the velocity [*inaudible*].”
15. **Unidentified student:** “Reset it and get rid of the walls.”
16. **Unidentified student:** “I think the confusing part at least for me with that demonstration is that, um, there’s nowhere to account for the force up there.”
17. **Charles:** “Right.”
18. **Unidentified student:** “And the force is what gives it a positive acceleration. Like, I get what they’re saying about how it’s always negative acceleration, but there’s no way to account for the force.”
19. **Charles:** “Well, let’s see if we can, though. We can’t see it, but let’s see if we can represent it.”
20. **Unidentified student:** “The acceleration—”
21. **Unidentified student:** “Do you have more than one thing accelerating on it?”
22. **Unidentified student:** “There’s only one acceleration, right?”
23. **Charles:** “Well, there’s...you can have...so remember when I...what causes—and you guys have just identified that—what causes acceleration?”
24. **Unidentified student:** “Force.”
25. **Charles:** “Can we have—in a tug-of-war—can we have more than one force on an object?”
26. **Unidentified student:** “Yes.”
27. **M:** “All the forces combine to make acceleration.”
28. **Charles:** “Right, right.”
29. **M:** “So all I’m showing is that, like, velocity can change because of acceleration, but it doesn’t work the other way around. I put acceleration at two and zero velocity as the starting one, and the velocity went up, but if I have two velocity with zero acceleration, it’s just going to be a straight line.”
30. **Unidentified student:** “But you had to have had [*inaudible*]—”
31. **M:** “You don’t need acceleration to be going.”
32. **Charles:** “So to...to summarize your point, you, your, your experiment there suggests that—”
33. **M:** “Velocity only changes with acceleration, so there has to be an acceleration to make it do that.”
34. **Charles:** “So you said acceleration can change a velocity, but a velocity cannot change an acceleration.”
35. **M:** “Yeah.”





**Figure 5: PhET's Moving Man simulation.**

After the students entertained a sidebar discussion about how the normal force prevents a ball resting atop a table to smash through it and continue toward the ground, Charles allowed S a chance to give a metaphor of his understanding:

36. **S:** “[*Stands up.*] For people who say zero [acceleration at the top of the trajectory], I have a really good example, dig: Imagine a box, a really heavy box, is sliding down a hill, and you’re here to stop the box [*puts his hands out in front of him*], rather than touch the box, you’re exerting a force onto the box [*pantomimes pushing a box*], and instead of pushing it back [*steps back*], the whole time you’re exerting the same exact force. The box is going to slow down and you’re going to push back the same exact way. You’re pushing the box the same amount of force right when you touch it to when you’re pushing it forward [*pushes forward on imaginary box*]. A heavy box—”
37. **Unidentified student:** “I understood what you guys were saying right up till that example.”
38. **S:** “No, no, no. M, would you get up [*motions toward M; M stands up and walks over to S*]? Okay, just imagine M is the heavy object and he’s running at me. Now I’m pushing with the same exact force [*pushes on M*] until I gain my momentum to push him back [*pushes M forward*]. So his force is going to push me back, since my force will cancel him out—just like gravity and the ball.”
39. **M:** “I see what you’re saying.”

40. **S:** “I will push him back and exert the same acceleration, except that I will win in the end, just like gravity and the ball.”
41. **Charles:** “So now we could clearly see about this example that two people and two forces: the force of M, force of S... So the, ah, so now but and here the power of analogy is...or I guess the trap of analogy is to be sure all the same factors are present in this case. So you guys are identifying forces: a hand and gravity. So we’ve got to keep track of when and where those forces act on the object.”
42. **Unidentified student:** “Can I? [*Points toward the board.*]”
43. **Charles:** “This is great. You guys are doing an awesome job in this discussion.”
44. **Unidentified student:** “So the initial acceleration is from me going like this [*off-camera*], right? And then and so as I—like when we had it at zero, and then there was acceleration acting on it. As soon as I let go, there’s no forces acting on it except for gravity. And that’s deceleration. It’s the only force acting on it. It has a positive velocity, but the only thing acting on it is gravity in a negative acceleration. And then as soon as it gets to the top, that’s when its velocity has finally stopped, and its acceleration takes over and starts the velocity in a positive motion downward—or negative motion downward.”
45. **Unidentified student:** “The thing that’s stopping me from completely agreeing with that is at the top of its path, there’s a problem, because as soon as it starts to come down, I agree with you completely: that it’s a completely negative acceleration. But at the top of its path I still think it’s zero, because of its velocity—”
46. **S:** “Don’t get velocity and acceleration mixed up.”
47. **Unidentified student:** “I’m not.”
48. **S:** “You are.”
49. **Unidentified student:** “You are, because as soon as I let go there’s no more positive acceleration on it. As soon as I let go, there’s only positive velocity; there’s no more acceleration going upward. So the acceleration, like when we did the thing yesterday, will slowly, slowly drop until it gets to zero, and then acceleration in the opposite direction is pulling it down. There’s no acceleration up because as soon as I let it go, there’s no force making it go faster upward—that would be the acceleration. Velocity is constantly—say, it’s like five meters per second and this is going 10. As it gets to, like, after five seconds, it will stop and it will start to go down with the acceleration.”
50. **Unidentified student:** “I got it. I got it. We’re good.”
51. **S:** “Do you still believe it’s zero?”
52. **Unidentified student:** “No, I understand it now.”

### Discussion of Charles’ Case

What is stunning about this example is the spirited manner in which the students—and not just a few of the usual suspects—truly engaged the concept of velocity versus acceleration, so much so

that at points Charles could not get a word in edgewise (responses 5 to 7). The question was simply phrased, but it pertains to an idea that often causes confusion among physics initiates: the difference between velocity and acceleration. Charles facilitated a forum that granted the students free expression of their thoughts and effectively guided from the side<sup>11</sup>, inserting himself into the conversation only when he found it necessary to refine a point (responses 23, 25, and 41) or ensure that those who wanted to express their ideas but had not yet seized the opportunity got their chance, as in the case of S. By permitting his students this free rein over class time, they remained fully engaged with the concept for more than 15 minutes and were able to help one another refine their understanding collectively. We cannot conclusively make any claim that the Thought Cloud helped facilitate the discussion in Charles' class; however, we believe that by capturing and then displaying each student's or student group's idea enables teachers and students to engage in discussion of myriad viewpoints, some of which less confident students might have otherwise kept to themselves.

### Sam's Use of the Thought Cloud

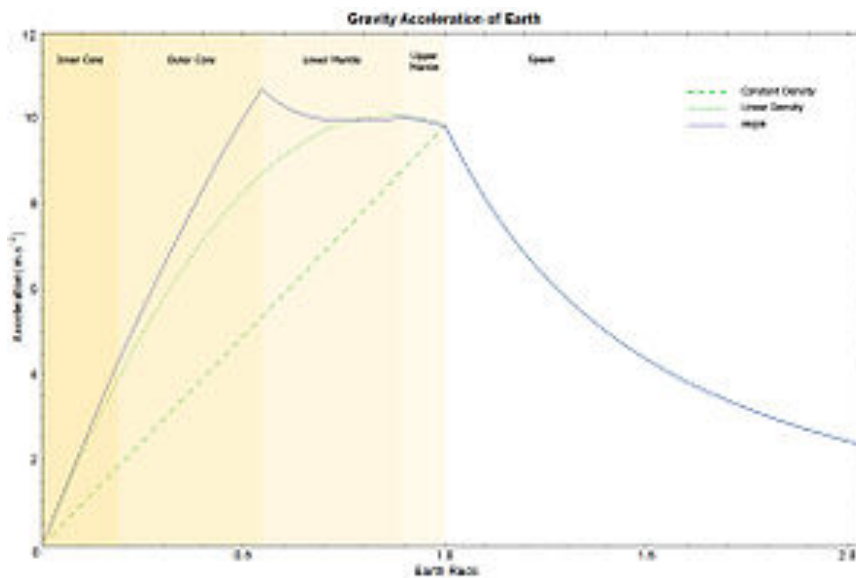
Sam had similar success in moderating debate among his students using the Thought Cloud. After a weeklong lesson plan in early April based on pendulums, which was created chiefly by the Design Team leader, Greg, and incorporated version 2 of the Thought Cloud for everything from prompting in-class discussions to recording and reporting lab results to answering homework questions, Sam used the last day to facilitate a discussion around one of the homework problems: "Does the period of a pendulum increase or decrease as you go deeper into a pit?" Almost all the students answered that the period would decrease, except for W. So Sam decided to reframe the question: "Does the acceleration due to gravity increase or decrease as you approach the center of the earth?"

1. **R:** "Gravity at the center of the earth would have to be infinity if it just kept increasing, right?"
2. **Sam:** "That's interesting reasoning. So grav— But, but, so you're saying gravity and period are related how?"
3. **R:** "Well, the formula says..."
4. **Sam:** "What formula is this? [*Goes up to the whiteboard to record the formula.*]"
5. **R:** "T equals two pi times the square root of ..."
6. **Unidentified student:** "L over g."
7. **R:** "L over g. So as the acceleration due to gravity increases the period decreases, except the acceleration due to gravity is not increasing in a deep pit; it's decreasing, right?"
8. **J:** "No, unless it were a really deep pit, the mass below you would be way greater than the mass above the sphere below you, so it wouldn't counteract gravity enough. The period might decrease. The decrease in period might be a bit smaller because of that factor, but I don't think it would change the overall result."
9. **Sam:** "So you would think the period would be about the same."
10. **Unidentified student:** "The period would decrease."
11. **Sam:** "The period would decrease."

12. **J:** “Yeah, I mean, like, the overriding factor is that you’re getting closer to the center of the earth, and unless it’s a really deep... So if, like—”
13. **Sam:** “Say it’s a really deep pit. A mile deep.”
14. [*Students talk over one another.*]
15. **J:** “If you think of the mass of the sphere below you there, it would still be greater, especially since what’s down there is liquid metal, which is much denser.”
16. **Sam:** “What would be greater? Sorry. We’re talking about gravity and period, and I’m trying—”
17. **J:** “So at the bottom of a deep pit, I would say that acceleration due to gravity would be greater, especially first because the mass below you is a huge amount, like, it’s still greater than the amount on the surface even if it’s a smaller sphere. Um, and also—”
18. **Sam:** “The amount on the surface. What do you mean by that?”
19. **R:** “Wait, I think we can—”
20. **Sam:** “So the mass below you is still so much.”
21. **J:** “Yeah, it’s greater than the mass at the top of the pit and especially because part of the mass below you is the core and that’s, like, liquid metal, which is much denser than what would be above you.”
22. **Sam:** “So you would be closer to that denser material.”
23. **J:** “But even without that, the amount of stuff below you would be way greater than the amount of stuff above you.”
24. **Sam:** “Okay, so let’s have some more opinions about this.”
25. **N:** “I think since it’s deeper, the atmosphere would be thicker, hence there would be more friction, so there would also eventually be a decrease from that.”
26. **Sam:** “How does friction affect period? I don’t see it in that equation. [*Points to whiteboard.*]”
27. **N:** “It would make it less, at least after one swing.”
28. **Sam:** “Less?”
29. **N:** “Yeah.”
30. **Sam:** “So the [*inaudible*] would speed up?”
31. **N:** “Because the period decreases?”
32. **Sam:** “Yeah, the [*inaudible*] would speed up.”
33. **N:** “Maybe it wouldn’t speed up, but there would be much less of an angle, so the period would be less.”
34. **Sam:** “The period would be less. But how would the angle affect it? Oh my gosh, we’re opening so many cans of worms here. So N has brought up some interesting things here: She wants to talk about the friction, the angle, and all these factors that affect the period. Man, we have a lot of work to do.”
35. **J:** “If the sphere were of uniform density—wait, no, never mind. Oh, wait. No.”
36. **Sam:** “Alright, alright. Hold on, J... So since T is just laughing hysterically over here, let’s hear what T has to say.”
37. **T:** “Um, I have no idea.”

38. [Sam sits next to T.]
39. **Sam:** “No idea?”
40. **T:** “No.”
41. **Sam:** “Wait, so, T, tell us about gravity. You know gravity. You’ve taken a test on gravity. On the surface of the earth what contributes to the acceleration due to gravity if you’re in a pit? [T looks at Sam.] Is it greater or less, do you think?”
42. **T:** “Greater.”
43. **Sam:** “Acceleration due to gravity is greater if you’re in a pit? How many people here think acceleration due to gravity is greater in a pit? [Sam raises his right hand; students who agree follow suit.] J, T—T, put your hand up. About half. How many people think acceleration due to gravity is less in a pit? [Sam raises his left hand; students who agree do the same.] Wow, we have a divided class.”

H offered to go up to the whiteboard to show why he believed  $g$  would decrease. He started by pointing out that assuming uniform density, mass is proportional to volume, and then wrote the equation for the volume of a sphere. Next, by plugging that equation into Newton’s law of universal gravitation, H evinced that  $g$  is proportional to  $r$ , thus as  $r$  decreases so does  $g$ . Sam remarked that H’s explanation was “masterful,” but J had a problem accepting that they could treat the earth as a uniformly dense sphere. To solve J’s quandary, Sam pulled up two graphs from Wikipedia: the earth’s radial density distribution according to the Preliminary Reference Earth Model and the earth’s gravity according to that same model, which shows that earth’s gravity reaches a peak at the surface, stays about the same in the upper mantle, then peaks again between the lower mantle and outer core, after which it drops to zero at the center of the earth (see figure 6). Jeff asked N to analyze the graph, which was projected onto a screen next to the whiteboard.



**Figure 6: The graph of earth’s gravity that Sam pulled from Wikipedia.**

44. **Sam:** “N courageously maintains that even though H proved that acceleration due to gravity decreases if the earth is uniformly dense, that in fact it increases. So, N, having inspected this graph, what have you found?”
45. **N:** “If you don’t go below the upper mantle, then the gravity will increase, but then if you go farther than that to the lower mantle, it starts decreasing, and then it increases again, which is just sort of weird.”
46. **Unidentified student:** “But what if it was a deep pit?”
47. **Unidentified student:** “A really deep pit.”
48. **N:** “My question is, How deep is deep?”
49. **Sam:** “Let’s define deep. How deep is deep? If I had the most advanced shovel possible, how far could I dig? [*Students talk over one another.*] So what is the deepest mine on earth? Does anyone know?”

Sam directed N to look up the deepest mine on Google, which she found to be 2.4 miles, and asked N to locate where the mine would exist on the graph. N was having difficulty, so Sam asked O to come up to the board.

50. **Sam:** “O, this is what I want you to tell us: Does the acceleration due to gravity go up or down if you’re two miles deep?”
51. **O:** “It’s not affected very much. [*Students laugh.*] It’s just a small amount.”
52. **Sam:** “So the answer to our question actually is that the period of a pendulum doesn’t change. Thank you very much. No, no, but O, what if it were just deep enough to see a change? What direction would it be going? Up or down?”
53. **O:** “It goes down.”
54. **Sam:** “Which way?”
55. **O:** “It goes, um...”
56. **Sam:** “As you dig deeper and deeper, O, which way are you going on the graph?”
57. **O:** “This way [*points left*].”
58. **Sam:** “Yes, so as you start from the surface and go to the left, is acceleration going up or down?”
59. **O:** “Acceleration is going up, so the period is going down.”
60. **Sam:** “Yeah. So does everyone agree with this? Does everyone understand?”

Sam reviewed what they had just discussed and what they had discovered using the graph and then repolled the class as to whether the period of the pendulum would increase or decrease in a deep pit, and students reached a consensus that the period would decrease, since the acceleration due to gravity increases within the lower mantle, where a pit would be deep enough to see a change.

## Discussion of Sam's Case

Sam took a more active role than Charles did in his students' discussion, but Sam's students seemed as engaged as Charles' were, though Sam perhaps needed to prod them at times (responses 36 to 42 and 50 to 60). His coaxing and coaching (responses 54 to 57: "Which way?" "It goes, um...") "As you dig deeper, O, which way are you going on the graph?" "This way.") showed a skillful facilitation of discussion, one that not only ensured that as many students as possible got involved in the conversation but also carefully probed the ideas being put forth. Perhaps the best example of this skill came in his interaction with J and then N (responses 15 to 34): Sam was able to keep J from dominating the conversation and to get both J and N to clarify their answers through a series of thoughtful questions that showed he was listening to their ideas and was genuinely interested in exploring them. Like Kraig, Sam used technological resources in conjunction with the conversation at hand: In Kraig's case, he used the Energy Skate Park PhET simulation to resolve a difference among the students' contributions to the Thought Cloud; in Sam's case, he used Wikipedia and Google to retrieve information that moved the conversation forward.

## Discussion of All Three In-Class-Use Cases

Numerous unifying themes emerge from the cases we have presented: use of additional technologies to enhance students' understanding, exposure of student ideas that might not be voiced or acknowledged in the course of a traditional lecture, and, most important, student debate of and engagement in physics concepts. Some conversations were more robust than others, contributable to a handful of factors—the first and most obvious being the number of experiences the teacher and students had had with the tool prior to the observations we have described above. While Charles had enacted one lesson plan with the Thought Cloud and Sam, three, Kraig and his students had never used the tool before. Kraig admitted in an interview conducted in the summer of 2012, after a semester's worth of use, that it took him some time before he could claim ownership of the tool. After implementing a few lesson plans with the assistance of two researchers from our group, he decided to use it on his own and realized "instead of this being like this big, onerous thing that I need to work with these other people on, I can just...throw some content up there and do the lesson. I can take what I did last year and modify it, and this can be a last-minute thing, even."

In that same interview, Kraig acknowledged a certain level of skepticism at the start of his participation in the InterLACE project: "In the university setting, a lot of times, things work, and in a high school setting, nothing works." Charles and Sam, however, were more optimistic. Charles, who was no stranger to enacting design-based inquiry projects, like a collaborative trebuchet-building assignment he presided over in the fall of 2011, claimed in a similar interview conducted around the same time as Kraig's that his involvement with the InterLACE project encouraged him "to put my best foot forward." Sam, who was covering for the Design Team leader Greg while he was on sabbatical to devote his full attention to the first year of the InterLACE Project, was initially content to let Greg take the lead when implementing the Thought Cloud but became intrigued after

Greg demoed the tool in the classroom. So the second time the Thought Cloud was used in his classroom, he took a more active role. His students were asked to design their own experiments that would test the various factors that affect resistance in a wire, and Sam reported in a interview conducted toward the end of the summer of 2012 that “it was pretty exciting to see what [the students] came up with [in the Thought Cloud].”

These varying levels of enthusiasm might reflect each teacher’s attitude toward teacher-centered versus student-centered instruction. According to Hammer<sup>7</sup>, “much of the challenge for teachers [in adopting an inquiry stance] lies in coordinating inquiry and traditional content-oriented objectives. How teachers understand and undertake that coordination depends largely on their more general assumptions and objectives (p. 493).” As evidenced by Kraig’s reliance on the IRE stance and the manner in which he had students use the Thought Cloud, which required them to read answers aloud, as they would passages from a textbook, thus likely cuing the students to frame the activity as a passive intake of information rather than an opportunity for active sense-making<sup>8</sup>, Kraig seems to prefer the traditional, teacher-centric lecture style because it has worked well<sup>3</sup>: For Kraig, it has been “economical” in terms of time and classroom management.

Charles, on the other hand, expressed a proclivity toward student-centered instruction: “The number one environmental factor I want to affect with the activities that we do is student buy-in, student enthusiasm, something that...[is] going to drive our curiosity.... I wanted the kids to, first and foremost, have a highly engaging experience.” His attitude is writ large in the case we have presented above: Rather than keeping a tight rein on the conversation that erupted from the students’ ideas about velocity and acceleration, he had enough faith in his students to let the discussion flow where it needed to go. And the fact that his students felt confident enough to assume the responsibility of information exchange within classroom also speaks volumes about Charles’ prevailing attitude toward their ideas.

Sam was similarly focused on student engagement. He said at the start of the year he planned to teach his students using a form of Socratic method, intending to get them to interact with ideas “by prompting [the students] with questions”—a tendency that was evident in his interactions with J and N especially. His overall goal was to leave them “with a better grasp of how to do an experiment, of what a good experiment is.” One of the things he appreciated most about the Thought Cloud was that it “got [the students] closer to that realization of what a good experiment is because it gave them freedom...in a way where I could still maintain a little bit of control; I could still guide them.” This desire to maintain control made Sam perhaps the best dynamic orchestrator<sup>3</sup> of the Thought Cloud. He seemed the most nimble at balancing the structure of the lesson plan with adapting it to his students’ needs and ideas as they engaged with it. He was able to “scout ahead to see where [his students’ ideas] may lead and make judgments about which ones to follow”<sup>7</sup> (p. 515). He rose to challenge “to be versatile and to be able to improvise based on [his students’] interactions with [a computer-supported collaborative learning]”<sup>16</sup> (p. 1) technology such as the Thought Cloud.



A final factor worth mentioning is the physical layout of the three classrooms. How the classroom is configured can play an important role in the orchestration of the activities conducted within it<sup>3</sup>. While Kraig's students were arranged in a traditional setting of desks grouped in pairs forming four lines facing the front of the classroom, Charles' and Sam's students were seated in the round: In Charles' case, the students arranged their chairs in a U shape; in Sam's case, the students were seated at desks arranged in a conference-room-style square. The fact that Charles' and Sam's students faced one another and Kraig's students faced forward undoubtedly had an effect on the quality and quantity of conversation the Thought Cloud produced.

## Conclusion and Future Work

Simply implementing a technological tool to encourage classroom discussion of and engagement in science and engineering concepts does not guarantee that productive and rich conversation and argumentation will result<sup>16</sup>. However, we believe we have shown that classroom communication systems such as the Thought Cloud possess the potential “to create a truly active learning environment”<sup>4</sup> (p. 8). We have documented in the cases above clear examples of students and teachers stopping and authentically interacting with one another's ideas, and many of those thoughts might have never been revealed because more timid students' might have kept their ideas to themselves. From the outset of the InterLACE project, we never conceived that the tools we would create, like the Thought Cloud, would be one-size-fits-all silver bullets that magically transform teachers into design-based inquiry masters right out of the box, and we maintain that awareness even in light of the small successes that we have enjoyed so far.

There have been moments when the use of the Thought Cloud has fallen flat, and we are mindful that each of the teachers in our project has experienced challenges with how best to implement the tool in the classroom. Sam admitted he initially struggled with “trying to read through the ideas and...to then get [the students] to engage what they input,” and similarly Charles said he felt somewhat overwhelmed by “the pile of student responses—how I am going to parse it and give students feedback, thoughtful feedback that they're going to value.” Going forward, we will continue to examine the successes and failures of the implementation of the Thought Cloud so that we can improve the Thought Cloud and create more tools that promote collaborative design-based instruction in high school STEM classrooms. Future features will likely include tools that allow teachers to aggregate, sort, filter, or condense the rich data they receive from their students. Tools for students may include similar analysis features, as well as one that requires students to reference one another's ideas and build upon them, and a workspace that congregates their work from multiple sessions. In addition to creating such add-ons, we plan to expand from more traditional science investigations toward more engineering-driven, design-based experiments in which students collaboratively design and develop laboratory activities that explore and test their understanding of STEM concepts.

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