

# What We Learned by Moving Beyond Content Knowledge and Diversifying Our Research Agenda

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**Abstract.** The Physics Program at Chicago State University has been investigating student learning for the past eight years in an effort to construct an effective instructional environment for the urban physics student. In our initial work, the targeted analysis on student content understanding caused us to miss the specific attitudes, thinking, and reasoning skills present in our students. As our research focus began to shift to identifying these other skills, we began to identify specific student resources that foster an active learning environment in the introductory physics course. In addition, we began to uncover a set of coherent, robust content knowledge that we had previously overlooked. Research studies on collaboration in the classroom and work on identifying intuitive and formal reasoning has since provided a rich, complex picture of student understanding and has informed the development of our instructional environment.

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## INTRODUCTION

Thinking like a physicist involves much more than developing a strong understanding of content knowledge. It involves scientific thinking, critical thinking, and reflective thinking [1]. We have found that our students are capable of thinking like physicists but that they do not always engage in this mode of reasoning. We are interested in understanding the conditions both in the individual and in the community that lead to the activation of ‘thinking like a physicist.’

In this paper we focus on aiding students in connecting and resolving inconsistencies between their intuitive and formal knowledge. When we give our students a physics task they often respond quickly, with little analytical thought using intuition [2]. Students rarely stop to think about other types of knowledge that may lead to alternative answers regarding particular tasks.

## CONTENT UNDERSTANDING

Typically, when educators begin reforming the introductory physics courses there is often a focus on the evaluation of student content understanding. This focus often involves the use of standardized diagnostic instruments that have been accepted by many in the physics education community as good measures of student content knowledge. Many of these diagnostics

were developed as a result of detailed research into student understanding and there is little disagreement that these instruments do tell us something about student content understanding. But what they tell us is complicated and this has led to much debate in the PER community [3]. Even with the debate surrounding these instruments, when you tell someone that you are reforming your classes, the first or second question is often “How are your gains on the Force Concept Inventory?” We ask these questions because the majority of the physics education community knows this tool well. In addition, it is fairly easy to report a simple number during a five minute hallway conversation. The problem with this focus is that it does not acknowledge and show respect for the complexity of student knowledge.

Students in the calculus-based physics course at CSU typically achieve gains on the FCI of about 30% although that number has been as low as 20% and as high as 37%, despite a reformed instructional environment that utilizes a number of PER-based innovations. During class we often see a deeper understanding of the content than these diagnostics would lead us to believe. In response to this, in 2004, we conducted a series of one-on-one interviews in which we asked students to respond to a series of questions from the Force Motion Concept Evaluation by Thornton and Sokoloff. [See reference 2.] The questions we focused on involved a student pushing a sled on a frictionless surface. One of the questions

asks students about which force would keep the sled moving to the right at a constant velocity. One of the students we interviewed immediately said that you would need a constant force to the right. One explanation for this response is that this student does not have a correct, robust understanding of Newton's Laws. Another way to interpret this response is that this student is not engaging in the reflective thinking that characterizes 'thinking like a physicist' and is not accessing the physics knowledge she has built up from the coursework. She sticks with this answer for much of the interview until at one point she brings up Newton's Laws. The following is an excerpt from the interview.

"Because you've removed the ... push that caused it to move in the first place ... Newton's law. It's either the first or the second ... Okay. ... Newton's law says that an object that's in motion will remain in motion. So, it's going to remain in motion and that's why it wouldn't stop right away. ... Oh. Okay. I have to change that answer. Newton's law is saying that an object in motion stays in motion ... So, if you're pushing the sled you're causing it to move and you let go, let go, and you stop pushing it then the sled would continue to move ... but the motion would just decrease. The motion would decrease in velocity ... No, let me change that answer ... Okay, this is my final answer. If you're applying a force ... and you stop pushing it, Newton's first law says that an object in motion stays in motion"

This excerpt suggests that this student does in fact understand Newton's First Law as we described it in the physics course. She articulates the law, applies the law, and revises her answer so that it fits with the scientific community response. It is also clear that her intuitive response has a fairly strong status as she continuously goes back and forth between these two types of knowledge. The multiple choice questions she is responding to therefore are not really assessing her understanding of Newton's Laws. Instead they are assessing her ability to access these laws on this task. The excerpt suggests that this student has much of the formal content knowledge – more than the results of the diagnostic might suggest. It also reminds us that student knowledge is complex and reporting single numbers to describe the effectiveness of an instructional approach does our students a disservice.

The interview environment and the continued prompting for the student to explain their results is an environment that is somewhat supportive for the student. In this environment, although the interviewer is not helping the student come to an answer the student recognizes the instructor as someone who is trying to help them understand the material. A more supportive environment exists in the classroom where CSU students engage in discussion and group work with great facility. We often find that in these supportive environments CSU students engage in the

type of critical, reflective, and scientific thinking that we value [4].

## COMMUNITY AND INDIVIDUAL

There are a number of methods by which we look at student behavior in the physics classroom including video tapes of students working in the class, informal observations, and data from their participation on clicker questions. The following example shows how students utilize the support of the community environment to access formal physics knowledge in the context of vectors. Despite this improvement in performance, when the vector question was asked on an exam, students performed poorly.

We have been implementing clicker question sequences at CSU since 2007 [5]. These sequences typically consist of three questions asked in a row with the first question being the easiest of the three. For this particular question, students were given two vectors, **A** and **B**, and then were asked which vector resulted from the following operations: **A+B**, **A-B**, and **2A-B**. In a class of 16 students we had 69% of the students answering correctly on the first question. Because of the high success rate there was little discussion. On the second question (**A-B**) we saw students perform at the 81% level and on the final question (**2A-B**) we saw students performing at the 94% level. Students improved, despite the fact the questions were becoming harder and harder. We then asked a very similar question on the exam (**2B-A**), expecting that students would perform well based on their performance in the classroom. On the exam question only 41% of the students answered correctly.

There are two ways to interpret this data. We may conclude that students do not understand how to add vectors or we may conclude that students are not engaged in 'thinking like physicists' in the exam setting. The most common response to the exam question in which students were asked about the vector **2B-A**, was a vector that would result from **A+B**. This particular response suggests that this question is not assessing student understanding of adding vectors, instead it is assessing student ability to engage in reflective practice and activate the formal knowledge that they have developed as a result of the course.

## INTUITIVE AND FORMAL KNOWLEDGE

When confronted with physics tasks both students and experts will often bring a set of intuitive knowledge to the task. This intuitive knowledge may fit with the formal physics knowledge or it may contradict the formal physics knowledge. The

intuitive knowledge that a physicist brings to a physics task has evolved over years and years of experience. The physicist's intuitive knowledge is a result of collected experiences which include observations, discussions, and the knowledge of the formal physics concepts, laws, and rules. Rather than using instruction as a tool to replace student intuition, we want student intuition to evolve as a result of diverse experiences both in the classroom and out of the classroom. Part of aiding students in the evolution of their intuition is connecting the formal knowledge they have developed in the course with their initial ideas.

## MOVING THE COMMUNITY MODES OF REASONING TO THE INDIVIDUAL

We often see students engage in the scientific, critical and reflective thinking skills in the community environment. Unfortunately, we have seen a number of instances in which these modes of reasoning do not make their way to individual tasks such as exams and diagnostics. Two examples have been presented in this paper. Students often seem to enter a different reasoning mode during these tasks. In order to aid students in bringing some of the modes of reasoning from the classroom to the individual we have begun implementing new questions to encourage students to bring both the formal and the intuitive knowledge to each task they confront. These questions come in the form of pretests and are typically given to students after lecture instruction but before they engage in laboratories and activities.

On a select number of pretests we give students a specific question and then ask them to respond to the question in two ways. The first question asks them to respond "Without thinking too hard – What does your intuition tell you about ...?" The second question asks them to respond "How would you answer using the ideas from the physics class?" These questions are designed to help students activate both these forms of knowledge and see how they can resolve situations in which these ideas are inconsistent with each other.

Although we have limited data from these new pretests, results from a pretest on Buoyancy show some interesting results regarding how students look at the these different types of knowledge. This particular pretest involved the following question:

Two cubical blocks of equal volume are placed in water. Block A is found to rest at the bottom of the tank while block B is found to float as shown. **Without Thinking Too Hard!** What does your intuition tell you about whether the buoyant force on block A is *greater than*, *less than*, or *equal to* the buoyant force on block B? Explain. **How would you answer using the ideas from the physics class?**

The question was given to students after lecture instruction but before the activity on Buoyancy.

Possibly because these questions came soon after lecture many students gave responses consistent with the physicist view that because block A displaces more liquid it has a greater buoyant force. We found that 75% of the students in the class gave this response for both the intuitive and the formal question. We were expecting that students would respond differently on the intuitive piece and the formal piece because we have found that many students believe that a floating object would have a greater buoyant force. This shows that our students struggled to separate these two types of knowledge. When asked whether their answers would be different on the two parts of the pretest, one student gave the following response: "If it's a pretest and I really didn't know, they probably would be different. But since I was already taught it, my gut reaction would probably be my physics reaction ...". In addition, the two students who responded to this pretest with the intuitive response that the buoyant force on B was greater and the formal response that the buoyant force on A was greater happened to be the top two students in the class.

## HOW DO STUDENTS VIEW FORMAL PHYSICS KNOWLEDGE

As physicists we have certain ideas about what formal physics knowledge is and these ideas may not be the same for all physicists. For some, the formal physics knowledge is the knowledge of the definitions, laws, rules, and concepts that allow us to accomplish specific tasks. It is not clear our students think about the formal physics knowledge in the same way.

At the end of the Spring 2010 semester we did a series of interviews in which we have students respond to a set of questions from the Force Concept Inventory (FCI) and then asked them to think about whether they were answering the questions based on intuition or common sense or whether they were bringing in the ideas from the physics course. Despite the fact that students responded very quickly when asked this question, the majority of students stated that they were using the ideas from the physics course. But when asked to explain, students struggled to identify the specifics. The excerpt below was given after the student was asked "... so do you remember the specific idea from physics 1 that..." The student responds:

"I remember a lot of stuff, but I'm not exactly sure what you're.... you told us ...about a lot of things I mean you taught us about forces, velocity, acceleration ... quite a few things ... I just don't know exactly what you're referring to ... I know that because it's moving that means that I increase, ... How do I explain this? ...So I know something is happening, I'm not sure exactly ... like you're referring to. Like I know that it is this because obviously I'm moving it.

But I guess you're trying to say like what topic? ... Like sum of the forces equals mass times acceleration or..."

Although this student cited that she was using physics in her responses she was not using the formal definitions, laws, and concepts that would help her solve this task. When pressured to provide the formal physics, she lists a set of terms from the course and only at the end cites Newton's Second Law. This indicates a disconnect between my idea of the formal knowledge and that of this student. Eventually the student does cite NII and is able to use it correctly to respond to the question. Once the student states NII and states that forces would need to be equal since the object is moving at a constant speed the interviewer asks her to explain her chain of reasoning. Despite the fact that the student has just stated NII and has used it to respond to the question, she struggles to explain her answer.

"How do I know that? ...forgot that thing that you told us. I know how to explain it, I do, but it's not coming to me ...well I guess I can say that the reason I know it's the same magnitude - because the forces have to be equal if it's moving at a constant speed because if it was greater then I guess it would change - it wouldn't be at a constant speed. So if it's not - then obviously one of the forces would have to be greater ...the reason I know it's the same magnitude is for that reason, but they have to be equal if it's going to stay at the same. Like it's constant speed to me is like it is the same as sitting ..."

This excerpt shows that although she was able to cite the formal physics knowledge (NII) she has trouble seeing its relevance in responding to this question despite using this idea earlier in the interview. This could indicate some misunderstanding in what I was looking for during the interview and could mean that I have not explicitly defined what I mean by formal physics knowledge.

A little later on in the interview the student explains how she answered some of the questions and begins to recognize that intuition has played a role in her responses. She states "... Intuition thing - I think I should be working on more physics than on the intuition...I mean I think it helps but it should be physics...and in any case sometimes in physics you have to write it down...you have to draw yourself a picture...and think about it."

## CONCLUSIONS

As we evaluate student understanding of physics it is important to remind ourselves of the complex nature of student understanding and reasoning. When we look beyond individual content knowledge and focus on the 'hidden curriculum' we often uncover a rich set of student ideas.

In this paper we have shown that by looking for the 'hidden curriculum' we found a robust set of formal physics knowledge. We have also shown that students often struggle to connect intuitive and formal physics knowledge. In certain settings we certainly see students engaged in reasoning modes which are guided by intuition while in other situations they are utilizing the formal knowledge from the course. Both of these types of knowledge are important and we are not suggesting that we ask students to abandon their intuition. Instead, we are suggesting that it is important that students bring multiple sets of knowledge to a task and believe that this strengthens both the formal knowledge and the intuition. We hope to make this connection more explicit by creating a set of questions and activities that ask students to comment on both these intuitive ideas and the ideas from the physics class. In addition it is clear that we need to clearly articulate what we mean by these two sets of knowledge for our students and help them understand and appreciate the importance of both intuitive understanding and formal physics knowledge.

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