AC 2008-84: IMPLEMENTING RESEARCH–BASED INSTRUCTIONAL MATERIALS TO PROMOTE COHERENCE IN PHYSICS KNOWLEDGE FOR THE URBAN STEM STUDENT.

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Implementing research–based instructional materials to promote coherence in physics knowledge for the urban STEM student

Abstract

Funding from the National Science Foundation – Course, Curriculum, and Laboratory Improvement (CCLI) Program has allowed the physics program at Chicago State University to make major changes to the algebra and calculus-based physics classes through the implementation of innovative, research-based instructional materials. This instructional reform effort seeks to (1) improve learning for all students in the introductory physics classes at the inner-city university, (2) involve undergraduate science majors in the implementation, assessment, and creation of innovative teaching materials, and (3) document the effectiveness of the implementation in promoting student learning through the use of multiple assessment instruments.

Almost all students enrolled in these introductory courses are majors in the science, technology, engineering, and mathematics (STEM) disciplines. In order for these students to succeed as they move through their academic and professional careers, they require preparation that goes well beyond what the traditionally taught physics course often provides. Rather than developing a skill set that involves pattern matching and formula manipulation, students need to be trained in sense making and need to be challenged by problems that require deep conceptual understanding. In addition, students need to be able to utilize and go back and forth between different types of representations that those in the STEM disciplines regularly use to convey information about physical systems.

In this paper, we provide an overview of the project, discuss the departmental involvement in promoting the understanding of physics for the STEM student and provide an example of the research we are conducting to document the successes and challenges we face as the project progresses. We also highlight our research efforts in identifying the struggle students face in bridging between different types of knowledge and different types of representations.

Background

There are a number of model instructional materials in physics that have proven to be effective in promoting student understanding in the introductory physics course. Despite the fact that these materials are widely used, there is relatively little research documenting the effectiveness of these materials with different populations of students.[1] At Chicago State University (CSU), the implementation of research-based instructional materials has served as a vehicle for understanding the issues that the student at a comprehensive university faces when learning introductory physics. Because of the wide range of differences that exist among students at different universities, it is important to document the specific issues that each population faces and determine where specific materials succeed and fail. Our work utilizes the introductory algebra-based physics class (taken mostly by biology majors) and the calculus-based physics course (taken mostly by physical science and engineering majors) as a context for the research on student learning.

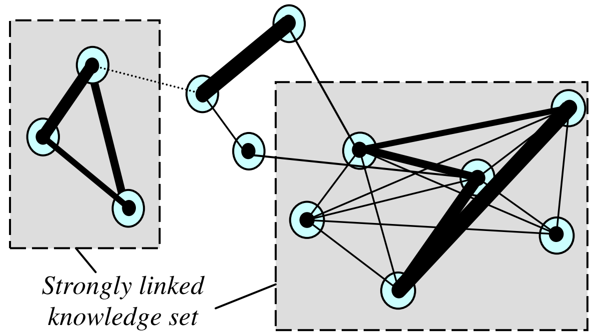
Because of the important role that representations play for all students in the STEM disciplines, we are currently engaged in developing instructional tools that emphasize the use of multiple representations. This paper discusses two specific aspects of our reform project: (1) the identification of difficulties in how students bridge between different representations and (2) the development of instructional materials that can be used to foster connections between multiple representations. This topic is especially relevant to the engineering student because physics is often one of the courses taken early in their academic careers. It is important that different STEM disciplines identify general skills that we believe are important to student success. These skills need to permeate throughout an instructional program and should be reinforced in all courses even if the disciplines are different.[2] Although the study we present focuses only on physics we believe that these results are general – and that the issues we raise are important considerations in any STEM education reform efforts.

A number of researchers have investigated issues students face with multiple representations and some have developed instructional environments that incorporate multiple representations to aid students in understanding different concepts. Rosengrant et al. have recently summarized the research in this area and discuss three main research questions: (1) do multiple representations help students learn concepts and problem solving, (2) what instructional innovations help students use multiple representations to solve problems, and (3) how does the specific representation used in a problem affect how students respond to the question.[3,4] The study presented in this paper adds to the body of research regarding how the specific representations used in a problem affect responses. Research on multiple representations is important to the STEM disciplines because it is directly related to how students form and organize ideas. By understanding how students treat multiple representations, we can get a better understanding of the fragmentation that often exists in student knowledge.[5,6] With this better understanding, we can begin to develop instructional materials that help students make connections between multiple representations. This can serve to strengthen understanding of the underlying physics concepts and establish more coherence in student knowledge.

Representations in physics can take on a number of different forms, including the representation of a concept or problem using qualitative or quantitative descriptions, depicting ideas in terms of graphs vs. equations, representing direction with vectors or positive and negative signs, etc. Despite the frequent use of mixed representations in physics and physics instruction, instructors rarely provide students with explicit instruction on the importance of multiple representations and the bridging of these representations. Because of this, students often develop fragmented sets of knowledge. This often leads to students responding inconsistently on questions represented in different ways even though the underlying physics concepts are identical.

One can model this fragmentation using a schema model of learning. As students are presented with information in the physics course, they develop schemas, consisting of closely connected pieces of knowledge. As students gain new knowledge, they form additional schemas that can either be well connected to each other or isolated from each other. Unlike experts, students often struggle with making connections between these different schemas and what ultimately forms are isolated sets of knowledge. If a particular question triggers a certain schema and the schema does not meet the goals of the task, it is often difficult for the student to trigger another, possibly more useful schema. An expert, on the other hand, has much more ease in going from one schema to another and therefore has a much easier time accessing the needed knowledge for a particular task.[7] A number of researchers have represented knowledge through graphs that depict nodes (of information) and links that connect the different nodes. Figure 1 is an adaptation of the representation described by Marshall.[8] Strong links are represented by thick lines while weaker links are represented by thin lines. If a student is given a particular task, the task will trigger a node (circle) that will then trigger other nodes with strong links. It will be difficult for the student to access the nodes with weaker links. The two shaded boxes, in the figure, represent isolated sets of knowledge – if either of these sets are triggered by some task it may be difficult for students to access knowledge from the other set because of the weak link between the two. It is important to note that when we discuss schemas we are not describing rigid structures – instead schemas are built on the spot and the way they are built depends on the particular task.[9]

Figure 1: Schema representation



As engineering and science majors proceed through their academic careers the importance of building coherence in their knowledge is extremely important to their success in solving complex, real world problems. There are currently a number of instructional resources that have evolved from physics education reform efforts that attempt to help students build connections. Unfortunately, only a few research studies explicitly seek to identify the fragmentation that occurs as students construct knowledge. One model instructional approach that emphasizes connections is the *Tutorials in Introductory Physics,* developed by McDermott, Shaffer, and the Physics Education Group at the University of Washington.[10] The *Tutorial* materials help students build connections between related topics by leading students through a linear sequence of questions, where in order for students to be successful, they need to build on their previous responses. These materials, and the philosophy behind them, serve as a starting point and a guide for the reform efforts underway at CSU and follow an approach that is consistent with what researchers know about how our students learn science.[11]

Methods

The project we are currently involved with, made possible from funding from the National Science Foundation – Course, Curriculum, and Laboratory Improvement (CCLI) program, involves the implementation and adaptation of research-based instructional materials and ongoing education research. In order to evaluate the effectiveness of these materials on promoting student learning we utilize a number of research tools common to the field of Physics Education Research (PER). It is the combination of these different methods that lead to the identification and understanding of fragmented knowledge. These tools include responses to multiple-choice diagnostic instruments, written responses to open-ended pretest and posttest questions, and one-on-one interviews.

In the introductory algebra- and calculus-based physics courses pretests are administered before each laboratory activity to assess the initial knowledge state of the student. Often, these pretests are given after lecture instruction but before students engage in the modified laboratory activities. Posttests are typically given on course exams, although in some cases they are given as graded or ungraded quizzes. Both pretests and posttests are integral components of the course design and serve as both instructional tools for the students as well as assessment measures for the researcher and teacher. Interviews, because of the large time investment, on the part of the researcher, are given periodically, when interesting research questions emerge from the pre and post-test data. In this study, data from an exam question prompted the need for student interviews. We performed interviews with student volunteers from the algebra and calculus-based introductory physics classes. During the interviews, students were given the same posttest question they had earlier in either an exam or quiz setting – they were asked to solve the problem and explain each of the steps they used in their solutions. Interviewers periodically interjected if statements were unclear or if further explanation was desired. Unlike a teaching episode, the interviewer did not ask guided questions in an attempt to lead students in a certain direction.

There are a number of limitations to this study. Because class size at Chicago State University is small (approximately 20 students in introductory physics classes) we do not have the luxury of large N studies. We are therefore presenting results that support our claims but larger scale studies would need to be done to strengthen our arguments. We believe that the use of qualitative and quantitative research methods address some of the problems associated with small N studies. In addition, as mentioned above, interviewees were volunteers so the sample for our qualitative methods is not a random sample of students in the introductory class. We should also note that the study presented is narrow – the student participants we work with are students at the urban comprehensive university.

In the next portion of the paper we describe how the use of pre and post tests, combined with one-on-one interviews, can reveal important information regarding the fragmentation of students' knowledge.

Context of the Research

The data comes from three introductory mechanics classes at CSU, located on the south side of Chicago. The school's undergraduate makeup is about 85 % African-American, 5 % White, and 5 % Hispanic (Undergraduate Physics is roughly 80% African-American and 56% female). Approximately 70% of the students attending CSU are female and most students who attend CSU reside within 5 miles of the campus and have attended public high schools in the area. Many of the students attending CSU are the first generation in their families to attend college and over 50 % of the students have at least one child.[12]

Two classes were calculus-based and one was algebra-based. Each of the three courses was taught by a different instructor, all of whom are involved with the CCLI project.

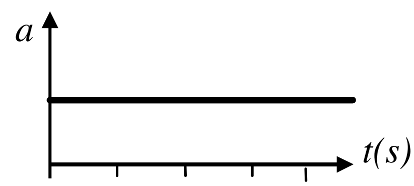
The posttest question shown in Figure 2, at right, was given as an exam question in the algebra-based course and one of the calculus-based courses and as a graded quiz in the second calculus-based course.

Figure 2: Posttest/Interview Question

A. Fill in the blanks in the chart below for each case of a moving train. The train can move North (+) or South (-) along a straight track.

+	+	
		Train is moving South, slowing down
-	-	
+	0	
		Train is stopped, about to move North

B. A cart travels in front of a motion sensor and slows down. The acceleration graph for the motion is shown below.



i. Is the velocity of the object positive negative, or zero?

ii. Sketch a qualitatively correct v vs. t graph for the motion.

The question involves two common representations instructors often use in describing motion in one dimension: *Positive and negative signs to denote direction* and *graphs of the different kinematics quantities.* In many texts, direction for 1-D motion is represented by positive and negative signs. It is only until students reach 2-D motion where vectors are introduced and used to convey direction. In many classrooms, students are confronted with both these representations in the text, in lecture, and in the laboratory. The two laboratories, students complete on this topic at CSU, titled *Descriptions of Motion* and *Acceleration in 1 Dimension* were developed by collaborators at New Mexico State University, California State University-Fullerton, and Buffalo State University. The laboratories have undergone a number of revisions at CSU to address some of the specific issues we observed with our students during both the implementation and the assessment of these materials. In this combination of laboratories, students utilize themselves, carts, tracks, and motion sensors to come up with the underlying ideas behind the concepts of position, velocity, and acceleration. As students develop these ideas, they often confront common misconceptions about the relationships between these quantities. For example, students often have the common misconception that a negative acceleration indicates slowing down.[13] To address this issue, during the lab, students construct a situation in which the cart is traveling toward the sensor and slows down. In this example the velocity is negative because the motion sensor sets up a coordinate system in which the positive axis is directed away from the sensor. Because the speed decreases, the sign of the acceleration must be opposite the sign of the velocity, or positive. These laboratory materials create a learning environment in which the students must confront and resolve common issues through their own observations and reasoning, with the help of an instructor asking guided questions. Students conduct a series of experiments and answer summary questions to connect the different types of graphs and help them relate the graphs to the different physical situations and the equations that describe them.

Analysis of open-ended responses

In order to evaluate the effectiveness of the laboratory activities, posttests, in the form of exam questions or quizzes, are administered. The exam/quiz question shown in Figure 2 consists of two parts. The first is a table in which students describe the motion of a train in words, as well as positive and negative signs, emphasizing that particular representation. The second part asks students to describe the velocity of an object based on the acceleration vs. time graph and a statement about the objects motion, emphasizing the graphical representation. If students had a coherent set of knowledge with strong links between these two representations of motion we might expect that student responses would, for the most part, be consistent on the two parts. We begin our discussion by first describing results for the two parts and then discuss the correlation between parts A and B.

Table 1 shows that students in the introductory physics classes performed fairly well on this portion of the question, although there is certainly room for improvement. We also notice a number of differences in the performance of each of the classes. These differences may be attributed to the number of differences in the administration of the posttest, such as whether the question was given as an exam question or a quiz, or whether the question was given immediately following the laboratory activity or not, etc. Although these differences are worthy of further investigation they are not important to the focus of this paper.

The second row in the table, in bold, involves a train moving south and slowing down. Since the train is moving south, a correct answer would involve students stating that the velocity is negative since it is moving south and the acceleration is positive since the train is slowing down. The Spring 2007-alg (S07a) and Fall 2007 (F07) classes performed fairly well on this question with 70% and 80% of the students answering correctly. Part B of the posttest question (shown in Figure 2) is a similar situation – students were given a graph showing a positive acceleration, and told that an object was slowing down. If students were consistent in their responses, those who completed row two correctly in the table would state that the velocity in this situation would be negative and the graph they draw would be below the *t-axis* and approach zero as time progressed. We found that despite the fairly good performance in the S07a and F07 classes on the related question from the table, we saw a great deal of difficulty with the question involving the graph.

Table 1: Results on posttest question

	Spring 2007 Alg, N=20	Spring 2007 Calc, N=19	Fall 2007 Calc, N=15	CORRECT RESPONSE
+, +	90%	95%	60%	N, speeding up
Train moving S, slowing down	**70%**	**42%**	**80%**	**-/+**
-,-	60%	26%	53%	S, speeding up
N, constant speed	80%	84%	73%	N, constant speed
Train stopped, about to move N	60%	37%	27%	0/+

As described earlier, the first question in Part B asks whether the velocity is *positive* or *negative*. In the S07a course only 35% of the students stated that the velocity would be negative despite the fact that 70% of the students indicated this in row two of the table. Students in the F07 course performed at the 33% level on this question despite 80% answering correctly in the table. This inconsistency shows that despite the fact that the questions are identical, in terms of the physics involved, and both questions are given as portions of the same question, students in these classes triggered different sets of knowledge in each of these contexts, most likely because of the different representations involved. Meltzer describes how questions about Newton's Third Law posed using a verbal representation and questions posed using a diagrammatic representation yielded different responses. He states that "the rate of correct responses on the diagrammatic version was never greater than 60% of that on the verbal version."[14] Our results, and those of Meltzer, both support the claim that representations play a very strong role in how the introductory student responds to questions on a single topic. One model that can account for these results involves the construction of isolated sets of knowledge.

In order to simplify our discussion of the specific inconsistencies we observed, we will only consider the results from a single class – the algebra-based physics course (S07a). A lack of a consistent response can be seen across the two parts (A and B) of the question as well as within a single part of the question. Part B consists of two separate questions – the first (i) asks students about the sign of the velocity, the second (ii) asks students to sketch a qualitatively correct velocity vs. time graph. Responses to B.ii. showed 70% of students drawing graphs that indicated speeding up - even though students were told that the cart was slowing down. In addition, 25% of the students drew graphs of velocity vs. time (B.ii.) that contradicted their responses in the first part (B.i.), regarding the sign of the velocity. Figure 3, shows an example of a student who clearly has a strong understanding of the material but gives an answer for the graph that directly contradicts her earlier response.

Figure 3: Sample student response

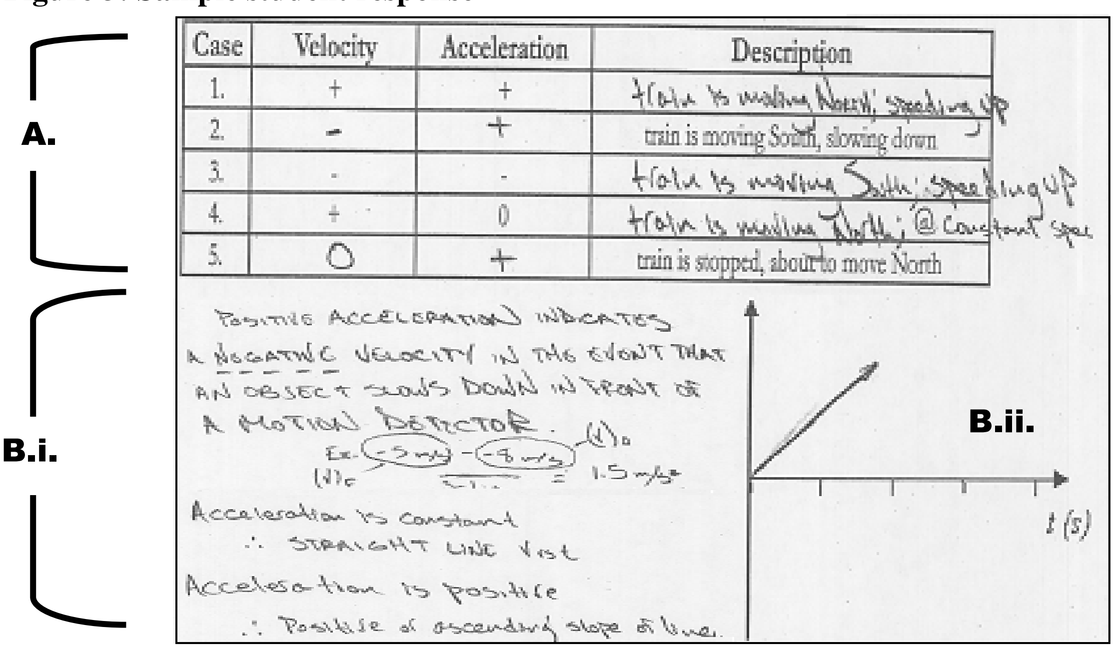


Table 2 shows the correlation between how students responded on the two parts of the second question (B.i. and B.ii.). These inconsistencies can be the result of a number of issues. Although we can attribute them to how students understand graphs our work seems to indicate that the causes of the specific responses are much more complicated than this and involve issues that go beyond simply content knowledge.

Table 2: Inconsistencies in Responses to Part B.

Results from algebra-based class (N=20)	*B.i. Is the velocity positive, negative or zero?*	
B.ii. Sketch a v vs. t graph	Negative velocity	Positive velocity
velocity below t-axis	15%	**10%**
velocity above t-axis	**15%**	50%
	other:	10%

Analysis of interview responses

In order to better understand the issues our students were facing on this particular question we requested volunteers from the introductory courses to participate in one-on-one focused interviews. During these interviews we administered the same question (from Figure 2) that students had seen on their written posttests to five student volunteers.

Responses from students during the interviews indicated a lack of a "robust" understanding of the positive and negative signs as a designation of direction. Although the students were able to correctly articulate what the positive and negative signs represented, they occasionally flipped their responses – this indicated a struggle the students were having between the formal physics knowledge from the course and a more intuitive knowledge. The formal knowledge being the fact that a negative acceleration can lead to an object speeding up or slowing down, depending on the direction of the velocity, versus the incorrect intuitive knowledge in which a negative sign implies slowing down (regardless of the direction of the velocity.) The following interview excerpt illustrates this:

> (At this point in the interview the student is explaining what the signs (of the velocity and acceleration) indicate about the motion of an object. Formal knowledge is indicated in bold while intuitive knowledge is indicated in italics.)
>
> "I can say **when it is speeding up the velocity and acceleration have to be the same which means it has to be a positive and positive** - that means speeding up
>
> or it has to be a *negative and negative - which means slowing down.* –
>
> well not - **when they're the same it's kinda like speeding up. When they are opposite it is slowing down.**
>
> So, if it is *a minus and a minus it is slowing - it's slowing down*
>
> no - I'm saying it wrong. A positive - ok - I'll say it this way …"

This example shows the student going back and forth between the formal knowledge and the intuitive knowledge. Although the student is able to state the correct, formal physics knowledge and apply this knowledge to this particular situation she continuously reverts back to the intuitive knowledge consistent with what researchers have described as a common misconception.[15] Because of this continuous flipping, we might say that this student's knowledge of the role of the positive and negative signs is not robust. In previous work, we have reported on a similar episode involving a student and her understanding of Newton's Second Law. The situation involved a question from the Force Motion Concept Evaluation (FMCE) involving a sled moving on a frictionless surface.[16] The student was asked 'what would keep the sled moving at a constant velocity.' The student, in this situation, continuously went back and forth between the formal knowledge, which suggested that no force is needed, to the intuitive knowledge, in which she felt that a constant force to the right would be required to keep the sled moving to the right.[17] It is important to note that in both these cases, we were not able to evaluate the robustness of student understanding from simply looking at the written responses. This is often the case with written responses – it is therefore very difficult for instructors to analyze the robustness of student knowledge from the types of assessment instruments typically used in our courses. In addition, it takes a particular type of question to trigger these inconsistent responses and provide evidence for robustness and fragmentation.

The second issue that was fairly common on the posttests, as well as in the interviews, was a student discomfort in sketching negative graphs despite laboratories that required students to explore these types of graphs.[18] One student, on part B, correctly stated that the velocity must be negative because the acceleration was positive and the object was slowing down - but later in the interview she drew a positive velocity vs. time graph. While describing her graph she stated "I still say positive … I know I said it was negative up there but…" A second student exhibited a very strong understanding of kinematics but also struggled with the graph of the velocity vs. time. On the first portion of part B (B.i.) she stated that the velocity was negative but, like the first student, she sketched a positive velocity graph which was consistent with the object speeding up. She stated:

> "if I go with this one - which is the upward sloping velocity - above the x axis - which means it's positive - but I still think my answer is wrong - but I can't prove it. … I still think my answer is wrong - only because it proves my positive acceleration - but it doesn't give me my slowing down motion …
>
> okay - this will be my final answer and I will take it if I am wrong or not … I am still sticking with my positive upward sloping velocity even though I feel it's wrong - … I like it better than the other two but I still feel it is wrong - …"

This excerpt is interesting because the student feels that she is incorrect and clearly identifies the problems with her response: "it proves my positive acceleration - but it doesn't give me my slowing down motion …" - yet, she is unwilling to draw a negative velocity graph, which would allow her to resolve these issues – it would also help her resolve the fact that the velocity must be negative, as she stated earlier in B.i.. This student has no difficulty understanding what the graph represents – she clearly states that she needs the positive slope for the velocity graph because of the positive acceleration – she clearly understands that she has drawn a positive velocity and has a graph that indicates speeding up. Many of the students who were comfortable stating that the velocity was negative in words in part B.i. opted to draw a positive graph in part B.ii. The excerpt from this interview provides evidence that there is a discomfort in drawing negative graphs. These are issues that go beyond content understanding and prevent this student from giving the correct response. It is also clear, from both the posttest questions and the interviews, that representations play an important role in these responses.

Addressing issues of coherence through implementing research-based instructional materials

There are a number of instructional materials currently available that address the issues students face in connecting across multiple representations. One such curriculum, that explicitly addresses the issue of multiple representations, is the Active Learning Physics System (ALPS) kits developed by Alan van Heuvelen.[19] In their paper focusing on work-energy processes, Van Heuvelen and Zhou describe how they utilize multiple representations throughout the course – indicating that students solved questions from the ALPS kits during lectures, recitations, and homework. One important point here is that the approach must permeate throughout an entire course. As curriculum developers and instructors develop materials for instruction, such as laboratories, problems, and discussion questions, the issue of multiple representations should be a consideration in the design of all these materials. In addition, it is our opinion that the connection between different representations must be made explicit and students need to be given background on why the use of multiple representations is important for learning the material and why it will be important in their future careers in the STEM fields.

Although an instructor can incorporate supplemental instruction that specifically addresses certain important ideas like conceptual understanding or multiple representations, it is important that the knowledge and skills we value as instructors are interwoven throughout a course. If one includes activities that focus on multiple representations but then assigns homework that solely stresses formula manipulation –students receive a mixed message.

Connections across multiple concepts and multiple representations may help build more coherence in student knowledge and help students organize ideas based on underlying principles.[20] Kohl and Finkelstein found that when multiple representations are used more often in the class the representation used in the problem had less of an effect on the way in which students answered.[21] The instructional materials we are developing as part of our project to restructure the introductory physics course at the inner city university is an attempt to provide an instructional setting where the knowledge we value, such as problem-solving, conceptual understanding, and connecting across representations permeate throughout all instructional modes.

One step in this direction is the use of multiple representations in laboratory and in lecture (through the use of clicker question sequences). Laboratories we are pilot testing at CSU as a result of a collaborative project with New Mexico State University, Buffalo State University, California State University – Fullerton often emphasize the use of multiple representations. As we adapt these materials to better fit the needs of our students we have found that these connections between multiple representations often need to be made very explicit. In addition to these laboratory materials, recent additions to our interactive PowerPoint lecture materials, as a result of a collaborative project with The Ohio State University and the College of DuPage, are now addressing this issue. The project involves the use of "clicker" questions that are part of question sequences, typically consisting of three to four questions given one after the other.[22] Many of the sequences we have developed as part of this project address the need to explicitly aid students in working with and connecting across multiple representations. Figure 4 shows one example of a question sequence that connects equations to the graphical representation of motion. We are currently investigating the effectiveness of the clicker question sequences in improving student understanding and student ability to build coherence in their knowledge of the underlying concepts.

Figure 4: Sample Clicker Question Sequence promoting multiple representations.

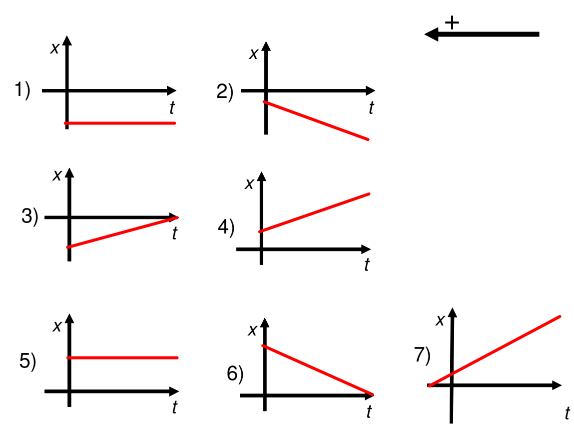
An object starts 1 m to the left of the origin and travels to the right with a constant speed of 3 m/s. The coordinate system is shown at right. Choose the equation that describes the position of the object as a function of time.

1) $x = 3\,{}^{m}\!/\!_{s}\,t + 1m$
2) $x = -3\,{}^{m}\!/\!_{s}\,t + 1m$
3) $x = 1mt + 3\,{}^{m}\!/\!_{s}$
4) $x = -1mt + 3\,{}^{m}\!/\!_{s}$
5) $x = -3\,{}^{m}\!/\!_{s}\,t - 1m$
6) $x = 3\,{}^{m}\!/\!_{s}\,t - 1m$
7) $x = -1mt - 3\,{}^{m}\!/\!_{s}$
8) $x = +1mt - 3\,{}^{m}\!/\!_{s}$

An object starts 1 m to the left of the origin and travels to the right at a constant speed covering 4 meters in 20 seconds. The coordinate system is shown at right. Choose the equation that describes the position of the object as a function of time.

1) $x = 4\,{}^{m}\!/\!_{s}\,t + 1m$
2) $x = -0.2\,{}^{m}\!/\!_{s}\,t + 1m$
3) $x = 0.2\,{}^{m}\!/\!_{s}\,t - 1m$
4) $x = 4\,{}^{m}\!/\!_{s}\,t - 1m$
5) $x = -4\,{}^{m}\!/\!_{s}\,t + 1m$
6) $x = -0.2\,{}^{m}\!/\!_{s}\,t - 1m$
7) $x = 0.2\,{}^{m}\!/\!_{s}\,t + 1m$
8) $x = -4\,{}^{m}\!/\!_{s}\,t - 1m$

An object starts 1 m to the left of the origin and travels to the right at a constant speed. The coordinate system is shown at right. Choose the graph that describes the position of the object as a function of time.



Summary

In this paper, we have provided an example of how we are using the analysis of student responses to construct a new learning environment and an instructional model at CSU that will benefit students at similar comprehensive, inner-city institutions. The study presented here deals with the specific issue of multiple representations and how they can be used to both provide evidence for the type of fragmented knowledge that students develop and how they can be used to aid students in developing more coherent knowledge. Bridging between different types of knowledge is essential for students pursuing careers in the STEM disciplines and this instruction on building coherence must permeate throughout a course or program. Although the study is in its beginning stages and further data is necessary to establish stronger claims, our results suggest that questions posed using multiple representations can be used to identify isolated sets of knowledge. In the data we presented, despite the fact that two questions were posed, in which the underlying physics was identical, students answered quite differently due to the fact that these questions utilized different representations. Our work adds to the growing body of research on multiple representations and supports some of the claims made by others conducting similar work.

The reform effort we are involved in to help students establish a more coherent understanding of physics, includes a variety of new instructional materials developed by CSU and its collaborators. These collaborators are spread throughout the country and each has a very different population of students. Because different populations of students have different strengths and weaknesses the collaboration on curriculum reform between these diverse universities is essential to the creation of effective materials for wide-scale use. The challenge for us exists in creating a coherent, integrated course in which students see direct connections between the different course components. To address the issue of coherence, we have developed a physics workbook that contains lectures, discussion questions, clicker questions, problem-solving tasks, and laboratories together into one unit that students follow throughout the course. This workbook provides students with a structure to the courses, in which they can easily see the connections between the various components. The workbook also provides a structure for instructors by providing them with a detailed map for how laboratory, discussion questions, etc. fit with the lecture materials.

This reform effort has involved over half the faculty in the Physics Program and over ten student researchers who received degrees or are currently pursuing degrees in mathematics or science. These students have been involved in curriculum development, research on student learning, and work as laboratory and classroom facilitators. Because of the large scope of departmental involvement in the implementation of the revisions and the research supporting these revisions, the instructional environment built around the physics courses has evolved into a community endeavor in which both faculty and students play an active role in program innovations. We believe that undergraduate students benefit in many ways from this large scale involvement in the instructional reform effort and the research associated with the project. Specifically,

- undergraduate researchers are given the opportunity to review and expand their physics content knowledge,
- undergraduate researchers are able to play an active role in the instructional improvement in the physics program and therefore share the responsibility for program improvement,
- future teachers involved in this work begin to recognize and appreciate the importance of identifying the knowledge state of their students.

Acknowledgements

The research and the reform efforts we are involved with are part of three National Science Foundation, Course, Curriculum, and Laboratory Improvement Grants (DUE #410068, #0618128, #0632563). The authors are also grateful to the contributions of Professors Coble, Bowen, and Kuhn who are both investigators on this project and are instructors in the introductory physics courses.

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[1] For other recent research on reform efforts at inner-city universities see R. Steinberg and K. Donnelly, "PER-Based Reform at a Multicultural Institution," The Phys. Teach., **40**, 108-114, (2002); M.S. Sabella "Implementing Tutorials in Introductory Physics at an Inner-City University in Chicago," PERC Proceedings 2002,79-82, (PERC Publishing, 2002); E. Etkina, K. Gibbons, B. L. Holton, and G. K. Horton, "Lessons learned: A case study of an integrated way of teaching introductory physics to at-risk students at Rutgers University," Am. J. Phys. **67**, 810 (1999).

[2] One of the new initiatives in STEM instruction is the move toward more cross-disciplinary instruction. One example of this is the growth of Integrative STEM Programs. For an example see http://teched.vt.edu/TE/STEM.html
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