Paper presented at the Learning Progressions in Science (LeaPS) Conference, June 2009, Iowa City, IA

USING LEARNING PROGRESSIONS TO DEVELOP AND IMPLEMENT AN INQUIRY MODEL FOR FORCE AND MOTION AT K-5 LEVEL

ABSTRACT: Science faculty and teacher curriculum specialists implemented a model for teacher development with intensive involvement of 34 K-5 teachers from two rural districts in NE Kentucky over a two-year period. The KY science standards were used as a framework for constructing learning progressions and linked guided inquiry activities in the content area of force and motion. The questions in this paper concern the development and structure of the learning progressions, their impact on developing curricular materials, and the effect they have on teacher cognitive development in the area of force and motion. The learning progressions were developed through an iterative process during which teachers in each grade level gained familiarity with content and pedagogy for all grades. This enabled the leadership team to learn from the teachers what would be meaningful at each grade level, in addition to the teachers themselves gaining comfort with science content. Pre-post testing of content knowledge, ongoing formative assessment, feedback surveys, and classroom observations permitted insight into teachers' initial knowledge base in these areas and changes in their conceptions of scientific ideas, as well as the impact of the project on student learning.

Diane Johnson, Lewis County Schools, 96 Plummer Lane, Vanceburg, KY 41179
Martin Brock, Department of Chemistry, Eastern Kentucky University, Richmond, KY 40475

Introduction

Newtonian laws of force and motion are a core concept in science, which allow for the integration and coherence of many key concepts, principles, and other theories (Michaels, Shouse, & Schweingruber, 2008), but they can be difficult for students to grasp in more than a superficial way. Numerous research studies have documented that students have trouble relating the formal ideas of motion and force to their personal view of how the world works (AAAS, 1993). Ioannides and Vosniadou (2001) interviewed 105 students from ages 4 to 16 to study developmental changes in the meaning of *force* and found that "the development of the meaning of force is a gradual and time-consuming process" (pg. 48). Thus, "conceptual change is a slow and gradual affair that proceeds by destroying rather than increasing the coherence of childrens' initial explanatory framework, thus preparing the ground for a new restructured conception that may or may not be finally achieved" (pg. 47). Another reason students find it difficult to understand force and motion is that traditional curriculum materials just present the ideas to students without helping them to develop these ideas (Kesidou & Roseman, 2002) or to restructure their thinking. Compounding the problem is the limited understanding of these basic concepts by elementary teachers, who are utilizing limited curricular materials, as well as their lack of understanding of instructional practices needed for facilitating conceptual change.

Although science standards at the national and state level have attempted to identify what a scientifically literate student should know and understand upon exiting high school (National

Research Council, 1996; Kentucky Department of Education, 2006), they are not of the grain size, especially for grades K-3, needed to design instructional units for several reasons. First of all, they are broad statements that do not explicate the necessary knowledge and underlying skills needed to achieve them. Second, they are written for grade bands, not specific grades, which leaves much guesswork for what is appropriate to teach at each grade level. Finally, they do not include common naïve and/or misconceptions that students might hold that need to be uncovered and confronted in instructional units to move students toward a more scientific conception. One method for helping both curriculum specialists and teachers design instructional units and to develop an increasingly more coherent and sophisticated understanding of foundational force and motion concepts involves the use of learning progressions (Duschl, Schweingruber, & Shouse, 2007).

According to Duschl, et al, "learning progressions are descriptions of the successively more sophisticated ways of thinking about a topic that can follow one another as children learn about and investigate a topic over a broad span of time (e.g., 6 to 8 years). They are crucially dependent on instructional practices if they are to occur." (p. 214) Typically, learning progressions are based upon research describing students' ideas at various ages (e.g., Driver, Guesne, and Tiberghien, 1985) but must be "partly hypothetical or inferential, since long-term longitudinal accounts of learning by individual students do not exist" (National Assessment Governing Board, 2006, p. 152). Alonzo and Steedle (2008) have proposed a 4-level learning progression for force and motion developed through the diagnosis of middle and high school student responses to ordered multiple-choice and open-ended assessment items, including interviews.

Our work required the development of a learning progression for force and motion K-5 from our state standards, science education and cognitive research, as well as "the logic of the science" (Merritt, Krajcik, & Shwartz, 2008), which was utilized to design professional development experiences for elementary teachers of science and to create correlated instructional units for each grade K-5. As Alonzo and Steedle (2008) reported, the development of our learning progression has been necessarily an iterative process involving feedback from teachers, teacher assessments, teacher observations during professional development, and currently from student assessments and classroom observations.

Project Description

The *Partnering to Progress* (*P2P*) project is a Kentucky state Math Science Partnership (MSP), which began in September, 2007 and has been extended through September, 2010. The partners consist of thirty-four K-5 teachers from eight elementary schools in two small, rural districts in northeastern Kentucky, science specialists from the Partnership Institute for Math and Science Education Reform of the University of Kentucky, a chemistry professor from Eastern Kentucky University, and one district curriculum specialist from each district. The goals of the project are to 1) enhance science content knowledge of K-5 teachers in physical science, specifically properties of matter, heat and temperature, and force and motion; 2) enhance the ability of K-5 teachers of science to implement instruction that leads to effective student learning of the identified content; and 3) develop administrators' knowledge and skills to provide effective instructional feedback and support of high quality science teaching and learning. Project activities consist of monthly cadre meetings with all partners, a 5-day summer institute, classroom observations, analysis of student work, and bimonthly principal meetings. Over 2400 elementary students will benefit from the coherent and progressive instructional units.

Principals from each school selected five teachers of science (2 primary, 2 intermediate, 1 special education), except for the two smallest schools (one from each district), which have one primary and one intermediate representative, to attend the monthly cadre meetings, which are focused on enhancing the science content and pedagogical content knowledge of the participating elementary teachers. From September, 2007 to May, 2008, the content focus was on force and motion. For five days in June, 2008, the participating teachers worked through the force and motion instructional units for two grade levels (K and 1, 2 and 3, 4 and 5) that were developed by the university partners and district curriculum specialists. Participating teachers implemented the units and trained all other elementary teachers of science across their district to use the units from August, 2008 to January, 2009. At this writing, all students, K-5, in both districts have been taught using the draft instructional units. Current project work is focused on properties of matter, and it is anticipated that these instructional units will be field-tested beginning August, 2009.

Methods

This paper describes the development of the force and motion learning progressions for grades K–5 built from content standards articulated through the Kentucky Program of Studies and their application to the development of instructional units for each grade.

The development process began by utilizing a science curriculum topic study (CTS) (Keeley, 2005) on the force and motion standards conducted by participating teachers and project facilitators during a monthly cadre meeting. The goal of the topic study was to provide the participating teachers a more in-depth understanding of the standards for which they were responsible for teaching by providing them with 1) the big picture of the topic by understanding expectations for adult content understanding, 2) instructional implications for teaching that topic, 3) the identification of associated concepts and specific ideas relative to that topic, 4) a summary of research findings on student learning for that topic, 5) an examination of coherence and articulation of that topic with other topics, and 6) a clarification of and linkage to state and district standards.

Observations of teachers during the CTS revealed misconceptions the teachers held about the concepts, their interpretation of the standard statements, as well as their ideas concerning instruction. For example, all but two teachers consistently stated that the application of a constant force resulted in a constant speed (consistent with previous research such as in Alonzo & Steedle, 2008). K, 1 and 2 teachers stated that they would just divide up teaching straight line and zig-zag motion, and since zig-zag was more complicated it should be taught in second grade. None of the grade level groups of teachers addressed the need for cementing an understanding of a reference point in describing the position of objects, even though this is explicitly stated in KY standards. (Teachers' responses to an open response question on the pre/posttest suggested that they did not understand the importance of this fundamental idea.) An overwhelming majority of teachers equated student understanding with the correct definition of terms. In fact, each subsequent cadre meeting included instruction on understanding current cognitive research on concept development and best practices for science vocabulary instruction. Not only did this information inform the design of learning experiences for the teachers at cadre meetings, it was used to begin to develop learning progressions that could in turn be used to develop the instructional units, including embedded formative assessments. For us, developing learning progressions became a way to bridge the gap between science education research, cognitive science research, professional growth needs of teachers and the lack of standards-aligned curricular materials.

Building from the CTS and using a process developed by the Assessment Training Institute (Stiggins, Arter, Chappuis, & Chappuis, 2004), grade alike groups of teachers in the cadre were facilitated in 'deconstructing' relevant KY state standards into knowledge, reasoning, skills and products. KY state science standards are organized into seven big ideas, with force and motion being one of those big ideas. Under each big idea, the standards are organized by understandings, skills and concepts, which are broad statements devoid of the underlying knowledge necessary for understanding. Because the teachers had limited understanding of both science content and associated pedagogy, deconstruction proved to be a very difficult task for them albeit a very revealing one for project facilitators. To further complicate the process, KY standards are not delineated for K-3 grades and contain only exiting standards for the end of primary. The K, 1st and 2nd grade teachers could not differentiate the deconstruction for each grade level. As we began to use our draft learning progressions, we found that sometimes the student activity helped to distinguish the progression as much as a learning progression statement. Observations and informal interviews with teachers as they worked in small groups during this process were also used to inform the design of subsequent learning activities for the teachers and for the development of the learning progressions used to design the instructional units.

Once these progressions were drafted, the project facilitators met with three university faculty to revise the learning progressions for each grade K-5, utilizing the CTS summaries, the deconstruction, observational data, research from science education on misconceptions, and research from cognitive science concerning concept development and change. Since the development of force and motion concepts rely on the use of data, measurement, and graphical representations, we also involved math education faculty to help insure that the mathematics we introduced (graphing, for example) was developmentally appropriate for each grade level based on national and state mathematics standards. Appendix A contains the initial version of our learning progressions that resulted from these synthesis meetings.

Naively, we thought that we would be able to utilize commercial materials and match them to the learning progressions to develop the instructional units for each grade level and that teachers would be able to help *develop* these units. We did not find any commercially prepared instructional materials (kits or textbooks) that matched our draft learning progressions derived from the standards. The materials failed to develop an in-depth understanding of key concepts across grade levels and often contained concepts that were not developmentally appropriate or standards-aligned (e.g., simple machines for 2nd graders). Pre-test data, observations during cadre meetings and of classroom instruction, and results from the use of several formative assessment probes informed our decision to change the focus of the grant from teachers developing units to teachers field testing units and providing suggested revisions based on implementation and analysis of student work samples. The data on participating teachers' content understanding strongly suggested that our monthly cadre focus needed to be on developing their content understanding, not developing units.

The first iterations of the force and motion learning progressions (see Appendix A) revealed three domains that provided an organizational scheme for the progressions, remaining professional development, and instructional unit development – reference point/position and time, description and interpretation of motion using words, pictures, graphs, charts and tables, and relating change in motion over time with push and pull and strength of push and pull. But as we began to design experiences for teachers and then students to help develop understanding, further delineation of these organizational domains were needed along with correlated and standards-based mathematical topics related to measurement, data collection, organization and display.

The current iteration of the force and motion learning progressions that evolved during the course of our project are found in Appendix B. Instead of three domains, we recognized the necessity of six domains for adequate concept development of force and motion in elementary students. These domains include motion, representation of motion, position, measurements of distance and time, and force. While some of these topics merge with increasing sophistication of the students, we found it helpful to keep them separate as discrete learning targets initially. In our learning progression, the representation of motion contains an important set of markers to gauge children's readiness to progress, because it provides increasingly abstract ideas of position, change in position, collecting and tabulating data, and eventually graphing and interpreting graphs of motion.

Revisions were necessary to the initial learning progressions because they were redundant and did not provide a clear description concerning what was unique to each grade level. Activities were mixed within the initial progression statements, which caused confusion about what was progressing in the force and motion domains. The current version (Appendix B) clearly identifies each domain, is less verbose and identifies what is unique to each grade level for each domain.

Using Learning Progressions to Draft Instructional Units for Grades K- 5

The reality is that most practicing classroom teachers do not have the time to analyze science education and cognitive science research findings for specific science topics and then apply their understanding to instructional unit design. Not only are these teachers responsible for teaching science, but most of the teachers involved in our project must also design and deliver instruction in reading, mathematics, social studies, arts and humanities and practical living/vocational studies. In addition to limited time, teachers must take broad standard statements and design appropriate learning experiences for the grade level they teach. However, many teachers have limited and faulty understanding of the concepts they must teach.

Contained within the Kentucky content standards by the 3rd grade level are emphases on the development of specific skills in students including observing, describing, comparing, graphing, and measuring change in position over time. The standards at this level identify pushing and pulling as forces in addition to rolling objects down ramps, and seek to have students relate strength of forces with the amount of motion. Cause and effect relationships are encouraged as well. These statements are somewhat broader than those contained in the *Atlas of Science Literacy* (2001). But even these statements emphasize learning targets of identifying motion categories, showing that change in motion is caused by forces and that strength of force is related to extent of motion changes.

In each case, the point must be made that it is difficult for teachers to construct a coherent set of inquiry-based lesson plans based on these standards. It is difficult to identify the key features of motion beyond specifying simply that motion is taking place.

For example, Kentucky standards, which are closely aligned to the *National Science Education Standards* and *Benchmarks for Science Literacy*, state that by the end of third grade, students will

- Describe the change in position over time (motion) of an object.
- Describe the position and motion of objects and predict changes in position and motion as related to the strength of pushes and pulls.

According to the *Atlas of Science Literacy* (2001), by the end of second grade, students will understand that

- Things move in many different ways, such as straight, zig zag, round and round, back and forth and fast and slow.
- The way to change how something is moving is to give it a push or a pull.

And by the end of fifth grade, students will understand that

- Changes in speed and direction of motion are caused by forces.
- The greater the force is, the greater the change in motion will be.

Learning progressions can be used to bridge these broad standard statements to what must happen instructionally on a daily basis. Table 1 illustrates how we used learning progressions to develop instructional units by providing the standard statements, one of the correlated grade level learning progression statement(s), and a correlated grade level sample activity summary from the draft instructional unit. In order to simplify for illustration purposes, related learning progression statements concerning representation, position, measurement and force are not listed. (See Appendix B for the complete progression that provides the related statements for each grade level.) Subsequent work (in preparation) will provide a fuller accounting of grade level activities correlated with all aspects of these progressions.

Table 1
Correlation of Grade Level Learning Progression Statement and Sample Activity to Standard Statement from KY Combined Curriculum Document

Standard Statements from KY Combined Curriculum Document	Correlated Grade Level Learning Progression Statement(s)	Sample Grade Level Activity from Draft Instructional Unit
By the end of primary Program of Studies: Understandings Students will understand that things move in many different ways (e.g., fast and slow, back and forth, straight, zig zag, etc.). Program of Studies: Skills and Concepts Students will observe and describe (e.g., using words, pictures, graphs) the change in position over time (motion) of an object. Related Core Content for Assessment Students will describe the change in position over time (motion) of an object. An object's motion can be observed, described, compared and graphed by measuring its change in position over time.	K – Identify that an object is in motion. Identify types of motion: is it straight line, is it fast, is it slow, how do you know?	Using their bodies, students demonstrate to the teacher, motion, no motion, motion in a straight line, and motion that is not in a straight line (zig zag or curvy). Teacher performs 16 separate motion demonstrations for students. For each demonstration, students hold up a card(s) that says either "moving," "not moving," "moving in a straight line," or "not moving in a straight line." The teacher charts whole class responses while asking students for evidence for their choices.
	1 – Describe motion with words as change in position within a familiar space. Trace motion of an object on a large sheet of paper.	The teacher performs a number of demonstrations for the students. As the students observe the demonstrations, they check their observations for each on a data sheet as moving or not moving and how do we know; moving in a straight line, moving not in a straight line (zig zag), speeding up, slowing down, changing direction and how do we know? Students compare their answers with others. The teacher charts whole class responses while probing for evidence to support their choices.
	2 – Determine elapsed time for an object to travel between two identified positions. Use map to indicate motion of an object or person.	Students observe demonstrations of motion and record the name of the demonstration and something significant about the motion they observe on an index card. Students then sort their observations of motion into categories that they think are the same in important ways and record their reasons for each category. Then, to better understand how things move, students regroup their cards into four groups – change speed, change direction, stationary or motionless, straight line and steady speed.

	3 – Use evidence to describe motion.	Students observe the motion of a wind-up toy and describe that motion as moving, not moving, straight line, not straight line, steady pace, not steady pace, fast or slow. Students collect time and position data for their wind-up toy and record data on a T-chart. The teacher models how to make sense of the data using his/her own set of data for a wind-up toy. The teacher creates a graph of his/her data and models how to interpret the graph as a way to describe the motion of the wind-up toy.
By the end of 4th grade Program of Studies: Understandings Students will understand that an object's motion can be described as its change in position over time and can be represented in a variety of ways. Program of Studies: Skills and Concepts Students will measure and record changes (using appropriate charts, graphs) in the position and motion of an object to which a force has been applied. Related Core Content for Assessment Students will interpret or represent data related to an object's straight-line motion in order to make inferences and predictions of changes in position and/or time. An object's motion can be described by measuring its change in position over time such as rolling different objects (e.g., spheres, toy cars) down a ramp. Collecting and representing data related to an object's motion provides the opportunity to make comparisons and draw conclusions.	4 – Interpret position vs time graph; be able to tell types of motion with graph (fast/slow)	Using a Go! Motion detector, students collect time and distance data for either a metal ball rolling down a track, a Kick-Dis traveling down the hall, or a super ball rolling across a table. Student groups post their data, and the teacher leads a discussion describing the data, looking for patterns in the data, and generalizing about uniform motion from the data. Students calculate their object's speed.
By the end of 5th grade Program of Studies: Understandings Students will understand that predictions and/or inferences about the direction or speed of an object can be made by interpreting graphs, charts or descriptions of the objects motion.	5 - Draw points on a graph for time/distance data and use resultant graphs to interpret types of motion	Students map and graph the motion of a meatball using a Go! Motion detector after viewing a 'stop-action' video of *On Top Of Spaghetti.* Students describe the motion of the meatball from position vs. time graphs as stationary, speeding up, slowing down, or

Program of Studies: Skills and Concepts Students will create and interpret graphical representations in order to make inferences and draw conclusions about the motion of an object. Related Core Content for Assessment Students will interpret data in order to make qualitative (e.g., fast, slow, forward, backward) and quantitative descriptions and predictions about the straight-line motion of an object. The motion of an object can be described by its relative position, direction of motion, and speed. That motion can be measured and represented on a graph.	moving at a constant speed

The processes of understanding the force and motion standards by conducting a Curriculum Topic Study on them, then deconstructing the standards into knowledge, reasoning, skills, and products, observing teachers as they discussed these processes, designing learning activities for teachers content and pedagogical content knowledge growth, designing learning activities for each grade level, K-5, and considering each process in light of the research has informed the development and continual revision of our learning progressions for force and motion. Each process provided a different lens for viewing the standards and subsequent student learning targets and activities. In addition, analyzing teacher assessment tasks and student assessment samples, along with classroom observations during the piloting of the instructional units provided new insights that have informed the current version of the learning progressions (Appendix B).

Using Force and Motion Learning Progressions to Design Professional Development and Instructional Units

Data collected throughout the project was used to inform the development and revisions of the learning progressions for both the design of the professional development experiences and the instructional units.

Informing Teacher Professional Development

Responses on the baseline teacher questionnaire administered at the first cadre meeting indicated that participants were in need of enhancement in physical science content targeted by the project:

- Three-fourths of the teachers had completed four or fewer college science courses. Only one-third had taken a college chemistry course, one-fourth a college physics course.
- 71% of the teachers reported feeling "very well-prepared" to teach reading/language arts, 40% felt very well-prepared to teach mathematics and social studies. In contrast, only 16% felt very well-prepared to teach science.

- 90% of the teachers reported feeling prepared to teach life science topics, 81% for earth science. In contrast, only 19% felt prepared to teach chemistry concepts, 16% physics.
- Only half the teachers felt prepared to analyze standards to identify key concepts and to identify likely student misconceptions.

One third of the teachers agreed with the statement, "I'm concerned that my background in science content is limiting my effectiveness as a science teacher." The pretest over force and motion content verified the teachers' perceptions.

All of the cadre teachers have completed pre- and posttests over force and motion concepts. The pretest consisted of 31 multiple-choice items and two open-ended items (maximum score of 4 on each). Using the draft learning progressions, a posttest was developed from the pretest items that were most closely aligned and better reflected the learning experiences during the cadre meetings for the teachers. The posttest consisted of 23 multiple-choice items and one open-ended item. Table 2 summarizes the pre/posttest data. The remaining elementary teachers of science in the two districts (non-cadre group) have completed the pretest and will complete the posttest after receiving training on the instructional materials. Therefore, this data is incomplete at this writing.

Table 2
Pre/Posttest Scores of Teachers

	Cadre group pre-test (SD) n=29	Cadre group post-test (SD) n=30	Effect size*	Non-cadre group pre-test (SD) n=82
Mean correct, 23 multiple choice items	48.2% (9.17)	60.2% (6.88)	1.31**	50.9% (9.72)
Mean rating, open response item (4 maximum)	1.8 (0.50)	2.0 (0.41)	0.4**	1.6 (0.54)

**p<0.001
*Effect size: Calculated by dividing the difference between pre and posttest scores by the pretest standard deviation

Pretest data of teacher content knowledge of force and motion, informal interviews with teachers, and district curriculum reviews suggested that the majority of the cadre teachers had a very limited understanding of the concepts, what the state standards identified that needed to be taught, and what experiences students would need to help them learn these foundational force and motion concepts. Use of the CTS helped to uncover the cadre's understanding of the concepts and the standards, while educating them as they conducted it. Although there was a significant difference between the pre- and posttest scores on the content test, many teachers expressed dismay that his/her posttest score was not higher. As one kindergarten teacher remarked in an informal interview,

> "I thought my score would have at least doubled. I felt that I have learned so much. I can tell you one thing, I may not have selected the right answer, but I could at least narrow my answer choice down to two. On the pretest, most of my answers were just guesses."

Responses to an end-of-year feedback survey indicate that participants feel their content knowledge has grown as a result of their project experiences thus far. The teachers were asked to use a 1 (low) – 5 (high) scale to describe their status prior to the project and their current status. Table 3 below contains mean responses.

Table 3
Responses to an end-of-year feedback survey (n=30)

	Prior status (mean)	Current status (mean)
Understanding "force and motion" concepts at a depth appropriate to support student learning	2.2	4.2
Understanding how key concepts of force and motion relate to the Core Content and Program of Studies for the grade(s) you teach	2.6	4.5
Deconstructing the Program of Studies and the Core Content for science to know what students are responsible for learning about force and motion	2.2	4.3
Understanding how the Learning Targets for your grade level build on those in previous grades and support those in later grades	2.3	4.7
Understanding the misconceptions that students commonly have about force and motion concepts	2.2	4.4

Participating teachers were quite positive about the project's approach to content enhancement. 83% reported that activities and discussion focused on deepening their content understanding made a "major contribution" to the effectiveness of the project's summer institute. 76% reported that content-focused activities and discussion were of "great value" to the monthly cadre meetings during the school year. Furthermore, two-thirds ascribed "great value" to cadre activities involving deconstructing standards and identifying student misconceptions about the targeted concepts.

Informing Revisions of Instructional Units

Paper/pencil summative assessments were administered pre/post instruction to students in grades 3-5. Currently, the only student results available are from some of participating teachers. The third grade test consisted of 17 multiple-choice items and 2 open response question (ORQ). The fourth grade test consisted of 18 multiple-choice items and 2 ORQs, and the fifth grade test contained 15 multiple-choice items and 4 ORQs. Assessment items were selected and/or developed to match learning progression statements. Multiple-choice distractors consisted of known misconceptions from the literature or ones that surfaced from observing teachers during professional development. Several of the assessment items warrant revision based on an item-analysis and unit revisions. However, several teachers commented that although the tests were more difficult than the one they normally used for force and motion, they could correlate each item to a specific progression statement and/or lesson learning target. Table 4 summarizes the participating teachers' students' pre/post test scores.

Table 4
Comparison of Students' Pre and Posttest Scores for Force and Motion of Participating Teachers

	Mean % Correct MC Pre	Mean % Correct MC Post	Mean ORQ 1 Pre	Mean ORQ 1 Post	Mean ORQ 2 Pre	Mean ORQ 2 Post	Mean ORQ 3 Pre	Mean ORQ 3 Post	Mean ORQ 4 Pre	Mean ORQ 4 Post
3rd Grade n=33	22.8**	45.4**	.94**	1.47**	.45**	1.27**	NA	NA	NA	NA
4th Grade n=102	47.3**	58.7**	.64*	.72*	.39**	.68**	NA	NA	NA	NA
5th Grade n=149	34.5**	46.6**	.73**	.96**	.88**	1.32**	.68**	1.43**	.84**	1.27**

**Pre/post difference is not significant*
***Pre/post difference is significant at p<0.005*

Even though the force and motion learning progressions were being developed and revised as the units were being developed and then piloted, there was a significant gain in student achievement from pre to posttest on the multiple choice portions of the test and on all open response questions except for one 4th grade item. An oversight on the 4th grade answer booklet, which did not contain the graphic from the test booklet, may have been responsible for the lack of improvement on ORQ 1. This suggests that the learning progressions and the correlated instructional units could account for some improvement in student understanding of fundamental force and motion concepts.

Conclusion

Because of the breadth of the standards, both at the national, state and local levels, the limitations of curriculum documents and textbooks "to recognize the importance of children's prior experience" (Duschl, et al, 2007), and the lack of science preparation of elementary teachers, there is a great need to provide curricula, curricular materials, and corresponding professional development to teachers that makes the wealth of available science education and cognitive research usable in the classroom. Learning progressions have tremendous potential as a means to do this. We have developed a learning progression for force and motion that spans kindergarten through fifth grade using an iterative approach of considering the logic of the concepts, available research about student understanding of force and motion, and what we learned through conducting a CTS, deconstructing the standards, observing and interviewing teachers during these processes, designing professional development experiences for teachers, and developing a set of instructional materials for each grade K-5.

While we were revising the learning progressions and considering their continuity with the middle and high school standards, we made the striking observation that all the major components for developing a scientific conception of force and motion are expected to be developed in the *primary* grades. The principle idea in kinetics, that forces are responsible for changes in motion, is expected to be developed by the second grade (see table 1 and the *Atlas of Science Literacy*, 2001). Added to this through high school are additions such as identifying forces, both invisible and visible, beyond pushes and pulls, the idea of acceleration, motion in a force field, and placing the analysis of forces and motion on a firm mathematical footing. The preliminary aspects of this, the deconstruction of the meaning of force and the meaning of motion and the impact of force on motion are contained within the primary standards. These include the idea of measurement of position and elapsed time, how to collect and organize data, and the beginnings of abstract representation of that data. Implied by this is a tremendous amount of conceptual thinking on the part of children, thinking that will reinforce and be reinforced by developments in mathematics and other domains of science.

Preliminary data from teacher pre and posttests of content and feedback surveys indicate that the learning progression was successful in improving the professional development experience of teachers, at the same time the PD experience informed the development of the progression. One weakness of our approach is that we did not begin with 'benchmarks' or levels of understanding for the teachers (Alonzo & Steedle, 2008), which would have helped us refine and differentiate PD experiences for the cadre teachers. Having these levels developed prior to designing the PD would have enabled us to make the pretest much more diagnostic and provided us with a clearer picture of the concept deficits from the posttests.

Since the instructional units were implemented this past school year, we do not yet have data about their impact on other assessment instruments (e.g., Kentucky Core Content Test). In fact, the most telling information about program success will not be available until 2012-2013, when this year's kindergarten students complete fifth grade. Other pertinent data not yet available, includes posttest data for the comparison group of teachers (non-cadre teachers) and pre/posttest data for non-cadre teachers' students in grades 3-5.

This work has shown that learning progressions have tremendous implications for designing curricula aligned with state and national standards. Without a clear path delineated for developing a scientific conception of a topic, especially one so fundamental yet counter-intuitive as force and motion, practitioners will be forced to either rely on the disjointed and non-aligned commercial products currently available or continue with their current activity mania, "teach, test, hope for the best" approach that does little to develop the concepts over time. An examination of the understanding of force historically and by students ages 4-16, (Ioannides & Vosniadou, 2001) confirmed that these approaches are not effective and that concept development is a gradual, time-consuming process.

In sum, a partnership of teachers and curriculum specialists worked with teachers to develop a novel approach to thinking about force and motion standards using learning progressions. In the course of this work, we showed that well-crafted progressions have a direct link with curricular planning for teachers, and that student work is positively impacted through this linkage. In addition, we reinforced what had already been known about the level of preparedness, willingness elementary teachers have for science topics, and the roles the standards play in their instruction. We currently are applying this general approach in the area of the structure and transformation of matter, and in the future expect to apply it to other science disciplines.

References

Alonzo, A. and Steedle, J. (2008). Developing and assessing a force and motion learning progression. *Science Education,* 1-33.

American Association for the Advancement of Science. (2001). *Atlas of science literacy vol. 1.* Washington, D.C.: American Association for the Advancement of Science and National Science Teachers Association.

American Association for the Advancement of Science. (1993). *Benchmarks for science literacy.* New York: Oxford University Press.

Driver, R., Guesne, E., and Tiberghien, A. (1985). *Children's ideas in science.* Milton Keyes, England: Open University Press.

Duschl, R., Schweingruber, H., and Shouse, A. (Eds.) (2007). *Taking science to school: Learning and teaching science in grades K-8.* Washington, DC: The National Academies Press.

Ioannides, C. and Vosniadou, S. (2001). The changing meanings of force. *Cognitive Science Quarterly,* 2 (1), 5-62. Retrieved May 2, 2009, from http://www.cs.pbs.uoa.gr/el/staff/vosniadou/force.pdf

Keeley, P. (2005). *Science curriculum topic study: Bridging the gap between standards and practice.* Thousand Oaks, CA: Corwin Press.

Kentucky Department of Education. (2006). *Combined Curriculum Document*. Retrieved January 9, 2009, from http://www.education.ky.gov/KDE/Instructional+Resources/Curriculum+Documents+and+Resources/Teaching+Tools/Combined+Curriculum+Documents/default.htm

Kesidou, S., and Roseman, J. (2002). How well do middle school science programs measure up? Findings from Project 2061's curricular review. *Journal of Research In Science Teaching,* 30, 249-270.

Merritt, J. D., Krajcik, J., and Shwartz, Y. (2008). Development of a learning progression for the particle model of matter. Retrieved January 22, 2009, from http://www.fi.uu.nl/en/icls2008/438/paper438.pdf.

Michaels, S., Shouse, A. W., and Schweingruber, H. A. (2008). *Ready, set, science! putting research to work in K-8 classrooms.* Board on Science Education, Center for Education, Division of Behavioral and Social Sciences and Education. Washington, DC: The National Academies Press.

National Assessment Governing Board. (2006). Science assessment and Item specifications for the 2009 National Assessment of Educational Progress. Retrieved January 22, 2009, from http://www.nagb.org/pubs/naep_science_framework_2009.doc.

National Research Council. (1996). *National science education standards.* Washington, DC: The National Academies Press.

Stiggins, R., Arter, J., Chappuis, J., and Chappuis, S. (2004). *Classroom assessment for student learning.* Portland, OR: Assessment Training Institute.

Appendix A

Initial Version of the Force and Motion Learning Progression

5th Grade
Math: Create line graphs

Describe motion using words, pictures, graphs, charts, & tables; Interpret words, pictures, graphs, charts, & tables

- Interpret data and make predictions about straight line motion
- Motion of an object can be described by its position, direction of motion and speed. (Note that all measurements of position and motion are made relative to a reference point or origin)
- Interpret line graphs and create line graphs with student generated data about straight line motion.
    - Position and time are used to create graphs for straight line motion
    - An object moving in a straight line at constant speed away from the origin (forward) is represented by an inclined upward straight line on an x vs t graph. (steeper=faster)
    - An object at rest is represented by a horizontal straight line on an x vs t graph.
    - An object moving in a straight line at a constant speed towards the origin (backwards) is represented by a downward inclined straight line on an x vs t graph. (steeper=faster)
    - An object moving in a straight line with changing speed is represented by a curved line on an x vs t graph
- Students will design experiments and use data to provide evidence to support the above statements.

Reference Point and Position & Time

- All measurements of position and motion are made relative to a reference point (origin)

Relate change in motion over time with push & pull and the strength of push & pull

- Distinguish between invisible (e.g. gravitational and magnetism) and visible forces.
- An object experiencing a change in motion due to a force will experience a greater change in motion if the size or strength of the force is increased.
- The change of motion of an object is less for a given force if the object has more mass.
- Students will design experiments and use data to provide evidence to support the above statements.

4th Grade
Math: division; create pictographs, bar graphs, line plots, Venn diagrams, and tables; analyzing graphs, tables, and charts, multiply units (ex. 2 cm X 2 cm = 4 cm^2)

Describe motion using words, pictures, graphs, charts, & tables; Interpret words, pictures, graphs, charts, & tables

- Compare motions of different objects
- Compare uniform and non-uniform motion; uniform motion is motion in a straight line at constant speed.

- Measure change in distance and change in time for straight line motion
- Measure uniform motion
- Calculate speed using a calculator
- Graph distance vs time as a class with teacher model and student data
- Interpret graphs of motion
- Predict from graphs (i.e. Where will it be later?)

Reference Point and Position and Time

- All measurements of position and motion are made relative to a reference point (origin)

Relate change in motion over time with push & pull and the strength of push & pull

- Investigate relationship of force and motion
- Force can change motion, speed, direction; changes in motion are caused by forces
- Applying force continuously, measuring motion
- Contrast continuous force vs instantaneous force (kick)
- Friction is a force as is gravity (qualitatively)
- The amount of change of motion is related to the size of the (net) force and the mass.

3rd Grade
Math: Multiplication and analyze tables, pictographs, bar graphs, simple pie graphs, line plots, and 2-circle Venn diagrams

Describe motion using words, pictures, graphs, charts, & tables; Interpret words, pictures, graphs, charts, & tables

- Measure time it takes for an event/motion using a stopwatch
- Collect distance, time data; for multiple measurements use median not mean
- Graph motion: Bar
- Transition to line graphs… only vs time for straight line motion. Teacher models how to interpret the graph and distinguish it from a map
- Straight line motion is different from other types of motion (circular, zig-zag, etc) –for this we can make line graphs.

Reference Point and Position & Time

- All measurements of position and motion are made relative to a reference object
- Connect to maps: Motion along a straight line can be illustrated or represented such as on a flat map; all types of motion on a flat surface can be represented on a map. Positions and motion on surface of earth can be represented on a globe.
- Assist with transition to x vs t plots (introduce origin as a reference point) for description of motion along a straight line.

Relate change in motion over time with push & pull and the strength of push & pull

- Force Circus (teacher notes below to think about)
    - Students can observe that an object can have more than one force acting on an object at a time (throwing ball up and the wind blows it sideways)
    - Students can notice that forces have direction
    - Students can notice that forces are sometimes balanced (tug of war—no overall (net) effect on motion—they cancel each other out)

- Force in the World Around You
  - Weight (gravitational force) as a force; show on spring scale
  - Air drag and wind on parachute; wind pushing; balloon deflating or propeller cars
  - A stationary object (ball) on an incline needs a holding force to keep it form rolling down the incline.
  - Students can observe that some forces are invisible such as static.

2nd Grade

Describe motion using words, pictures, graphs, charts, & tables; Interpret words, pictures, graphs, charts, & tables

- Measurement---Distance to the nearest cm, time using a stopwatch (exploration)
- Continue *MOTION CIRCUS*
- Motion Circus--- More sophisticated sorting of motion into categories---Circular
  - Categories: Change Speed, Change Direction (swinging, back & forth, etc), Stationary or Motionless {uniform}, Straight Line & Steady pace {uniform}
  - All of K and 1st, steady (straight line and constant speed){uniform}, periodic
  - Motion in the World around you
  - Use digital camera and tie to frame of reference

Reference Point and Position & Time

- Use digital camera and tie to frame of reference. All students can look at same picture and collectively decide to use same reference point to describe position of objects.
- Use Mr. Oscar to explore reference points
- Connect to maps: the positions of many objects both stationary and moving can be shown on flat maps and globes.

Relate change in motion over time with push & pull and the strength of push & pull

- Force in the World Around You
- Horizontal spring scale—hard and soft pulling
  - Spring scale vertical—hard and soft pulling—hang object which pulls the scale
  - The harder (stronger) you apply a force (pushing, pulling, kicking), the greater the change in motion can be (speeding up, slowing down, change in direction)

1st Grade

Describe motion using words, pictures, graphs, charts, & tables; Interpret words, pictures, graphs, charts, & tables

- Measurement—distance using the nearest cm as well as non-standard units, time by hour and ½ hour
- Continue *MOTION CIRCUS*
  - Include all of Kindergarten, changing speed, start & stop
  - Simple changes of direction
  - Motion in the World around You
  - Use digital camera and tie to frame of reference

Reference Point and Position & Time

- All students will use a common reference object (e.g.-teacher's desk)

- All measurements of position and motion are made relative to a reference object
- Connect to maps

Relate change in motion over time with push & pull and the strength of push & pull

- Force in the world around you
- Observation of…If you don't hold an object it falls to the ground
- Observation of…If it is not moving and you push it, it begins to move
- Forces that we apply by pushing, pulling, kicking, etc, can change motion
    - Magnets can push and pull one another. Magnets pull on only some things
    - Springs and rubber bands (hard and soft)
    - In order to prevent something from falling, one must "hold" the object or put it on the table

Kindergarten
Describe motion using words, pictures, graphs, charts, & tables; Interpret words, pictures, graphs, charts, & tables

- Measurement—use non-standard units to measure distance (cubes, links, etc), time is day, night, before, after
- Begin *MOTION CIRCUS* (limited/basic categories)—Describe in their own words what motion they see
    - Moving, not moving (stationary/motionless), zig-zag, straight line
    - Motion in the World Around You
    - Use digital camera and tie to frame of reference

Reference Point and Position & Time

- All measurements of position and motion are made relative to a reference object
- Describe the position of an object in relation to another object (up/down, above/below, moving closer to/further away)

Relate change in motion over time with push & pull and the strength of push & pull

- Experience push and pull (look at Sis. Hennessey's activities as a starting point)
    - Contact force
    - Hard and soft
    - Observations of pushes and pulls

Appendix B

Current Version of the Force and Motion Learning Progression

<table>
<tr><th rowspan="2">Grade level</th><th>Motion</th><th>Representation</th><th>Position</th><th colspan="2">Measurement</th><th>Force</th></tr>
<tr><th></th><th></th><th></th><th>Distance</th><th>Time</th><th></th></tr>
<tr><td rowspan="2">K</td><td>Identify that an object is in motion</td><td>Draw pictures of objects</td><td rowspan="2">Describe locations of objects in relation to self</td><td>Measure height of self</td><td rowspan="2">Tell time</td><td>Recognizing that pushing and pulling can start motion</td></tr>
<tr><td>Identify types of motion: is it straight-line, is it fast, is it slow, how do you know?</td><td>Draw pictures of self</td><td>Measure length or height of familiar objects</td><td>Discriminate between continuous push/pull and brief shoves and yanks.</td></tr>
<tr><td rowspan="2">1</td><td>Describe motion with words as change in position within a familiar space</td><td rowspan="2">Locate positions of objects on large sheet of paper</td><td rowspan="2">Describe locations of objects in relation to other objects</td><td>Measure distance between self and another object</td><td rowspan="2">Determine elapsed time between two events</td><td rowspan="2">Pushes and pulls are required to start an object moving</td></tr>
<tr><td>Trace motion of object on a large sheet of paper</td><td>Measure distance between 2 objects or discrete positions</td></tr>
<tr><td rowspan="2">2</td><td>Determine elapsed time for an object to travel between two identified positions</td><td>Create map consisting of a grid on sheet of paper showing where objects are located relative to an origin and grid</td><td colspan="2" rowspan="2">Identify a fixed origin to be used in describing and measuring positions of objects</td><td></td><td>Amount of push/pull affects extent of motion</td></tr>
<tr><td colspan="2">Use map to indicate motion of an object or person</td><td></td><td>Recognize that forces may change motion by slowing objects down or changing their direction</td></tr>
<tr><td>3</td><td>Use evidence to describe motion</td><td>Create tables of time and distance and relate to types of motion (fast, slow)</td><td colspan="2">Recognize that the distance an object travels is not the same as the distance from its initial position to its final position if it does not travel in a straight line</td><td></td><td>Show that surface type affects aspects of motion such as slowing an object down</td></tr>
<tr><td rowspan="2">4</td><td colspan="2">Create table showing how changing mass of an object results in different effects of force on the object</td><td colspan="3" rowspan="2"></td><td>Show that mass changes how force effects motion</td></tr>
<tr><td colspan="2">Interpret position vs time graph: be able to tell types of motion with graph (fast/slow)</td><td>Show that a continuously applied force may cause objects to speed up</td></tr>
<tr><td>5</td><td colspan="2">Draw points on a graph for time/distance data and use resultant graphs to interpret types of motion</td><td colspan="3"></td><td>Surface type affects motion through a force called friction, and that some forces are invisible, such as gravity and magnetism</td></tr>
</table>