Achieving Standards in Urban Systemic Reform: An Example of a Sixth Grade Project-Based Science Curriculum

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Abstract: A challenge for urban systemic reform initiatives in science education has been to achieve local, state, and national standards for teaching and learning. We have collaborated with teachers in the Detroit Public School System to design project-based curriculum materials that contextualize the learning of science in meaningful real-world problems, engage students in science inquiry, and use learning technologies. We present a sixth grade project-based science unit in which students explored the driving question "How Do Machines Help Me Build Big Things?" and address the science learning goals of balanced and unbalanced forces, simple and complex machines, and mechanical advantage. Twenty-four teachers and over 2500 students in Detroit participated in enactments of this project over 4 years. Student learning outcomes were determined for the three learning goals and inquiry process skills using pre- and postachievement tests. Achievement outcomes as measured by the pre/posttest show significant and consistently high learning gains, even as participation in the project increased to include greater numbers of teachers and students in successive enactments, and leadership of the professional development support for this project transitioned from university researchers to district teacher leaders. These results illustrate that materials which contextualize learning and support student inquiry as part of an urban systemic reform effort can promote learning of important and meaningful science content aligned with standards. © 2004 Wiley Periodicals, Inc. J Res Sci Teach 41: 669–692, 2004

A challenge for urban systemic reform efforts in science education has been to find a means of achieving local, state, and national standards for science teaching and learning across large numbers of teachers and schools. In addition to providing guidance for the sequence and

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presentation of ideas and concepts, science reform documents such as *Benchmarks for Scientific Literacy* (American Association for the Advancement of Science, 1993) and the *National Science Education Standards* (National Research Council, 1996) emphasize the teaching of science through inquiry situated in real-world meaningful contexts. However, research has shown that it is difficult to improve the teaching and learning of science to meet the demands outlined by these new standards (Anderson & Helms, 2001), particularly on a large scale in urban settings.

As part of a collaborative effort with the Detroit Urban Systemic Program to reform science education, researchers at the University of Michigan and Detroit Public School teachers have designed project-based curriculum materials that build from district, state, and national standards to support the development of integrated science understandings for middle school students. These materials not only support students' science learning, but do so through engaging them in inquiry about real-world problems, providing them with multiple opportunities to work with concepts, and integrating the use of learning technologies in instruction. The question remains, however, if these project-based science materials are able to help students achieve important learning goals aligned with standards, particularly as participation in the projects increases to involve greater numbers of teachers and schools. In this study we present an example of our work, a sixth grade curriculum project designed in collaboration with university researchers and Detroit teachers that builds from science standards while involving students in inquiry around real-world problems of interest to urban youth and uses learning technology tools to support their investigations. We explore the learning outcomes across 4 years of the project's enactment in Detroit middle school classrooms as participation in this project increased to include greater numbers of teachers and students in successive enactments, and leadership of the professional development support for this project transitioned from university researchers to district teacher leaders.

Addressing Standards: A Challenge for Urban Systemic Reform

The national standards challenge all educational settings to make dramatic changes in the teaching and learning of science (Anderson & Helms, 2001). These changes include fewer science concepts that are presented in more depth, with an emphasis on real-world application of science and interconnections between concepts; involving students in inquiry where they ask questions, design and conduct investigations, and support their conclusions with evidence; and highlighting the nature of science and the role of technology as a tool to support innovation in our society (AAAS, 1993; NRC, 1996). These are significant changes from traditional instruction in science classrooms, and difficult to put into practice. Initial attempts at reforms in science education to meet these goals have generally fallen short of the desired outcomes (Anderson & Helms, 2001).

Urban schools face their own unique challenges in terms of educational reform. These include overcrowded classrooms, lack of resources, difficulty attracting qualified teachers, student attendance problems, and low student scores on standardized tests (Lynch, 2000). Combining these challenges with the already difficult task of implementing sustainable standards-based reforms in settings where they are at odds with the prevailing culture and practices of schooling (Blumenfeld, Fishman, Krajcik, Marx, & Soloway, 2000; Tyack & Cuban, 1995) make the prospect of reforming urban science education appear daunting at best. Critics of the current standards-based reform efforts claim that these reforms ignore the lives and learning processes of students, particularly in urban settings (Seiler, 2001). They argue that, by placing emphasis on "western" science and achievement performance on high-stakes standardized tests, the norms, interests, and prior experiences of urban students are not utilized to promote scientific understanding and awareness (Seiler, 2001). Others argue that the standards reform movement weakens the efforts of urban science teachers, compromising their professionalism and disenfranchising students and teachers from the real-life implications of the curriculum (Settlage & Meadows, 2002). These criticisms highlight possible explanations for why studies have consistently shown the inability of top-down instructional reforms to take hold and be sustained without the support of the intervening party (Blumenfeld et al., 2000). We attempt to address these criticisms through our ongoing collaborative work with urban teachers and administrators in the Detroit Public School System.

Despite calls for more coherence, policies and practices for instituting reform are often contradictory (Newmann & Wehlage, 1995). Large urban school districts, such as Detroit's, have seen many educational reforms come and go over the years with most making little impact on the teaching and learning that occurs in the classroom. In the mid-1990s, Detroit, through the Urban Systemic Reform Initiative from the National Science Foundation, began to reform science and mathematics education throughout the district. Systemic reform has been promoted as a way to overcome the previously uncoordinated nature of change efforts in urban settings (Vinovskis, 1999) by addressing the dilemma of how to incorporate new content and pedagogical standards into old schools and school systems (Wasser, 1998). This reform model addresses the organization of different components within a large urban system. For example, within a school district, systemic reform refers to the coordination of curriculum materials development and adoption with assessment requirements and teacher professional development, and the creation of teacher and administrator leadership capacity to enable schools to make local decisions commensurate with the reform agenda (Blumenfeld et al., 2000; Goetz, Floden, & O'Day, 1995; Resnick & Hall, 1998).

In collaboration with the Detroit Urban Systemic Program (DUSP), our work as part of the Center for Learning Technologies in Urban Schools (LeTUS) attempts to address the shortfalls present in previous standards-based reforms. LeTUS is a joint partnership with the University of Michigan, Detroit Public Schools, Northwestern University, and Chicago Public Schools. A goal of LeTUS is to infuse the use of effective learning technologies in Detroit and Chicago schools at a systemic level to promote student learning. To accomplish this goal, LeTUS uses a combination of custom-developed curricula, learning technologies, and coordinated professional development for middle school science teachers in these urban settings (Blumenfeld et al., 2000; Singer, Marx, Krajcik, & Clay-Chambers, 2000). This is accomplished through a process of building on previous educational research and collaborating closely with Detroit Public School teachers and administrators to adapt and create sustainable reform (Blumenfeld et al., 2000). The collaborative partnership between our group at the University of Michigan and the Detroit Public Schools entails building capacity both within the district itself and in the relationship between the school district and the university on the multiple issues facing the teaching of science in the Detroit schools. These issues cover both policy and practice, and include technology enhancements and supports at the classroom and district level, the selection and articulation of district science content and inquiry standards, professional development opportunities for both teachers and administrators, and development of reform inquiry-based curricula in conjunction with classroom teachers and content experts. For example, one of the authors worked with the district leadership to orchestrate reform at the district level by advising on the development and articulation of their standards, their approach to learning, and the materials they used in science classrooms. Particular to this work, when LeTUS began, both teachers and administrators in Detroit claimed that classroom use of learning technologies would only be used if curriculum materials were developed that met district learning standards and effectively embedded the use of these technologies as an integral part of instruction. This became one of the primary foci in our collaboration with the Detroit Urban Systemic Program.

More details about the various aspects of this collaborative reform partnership are available elsewhere (Blumenfeld et al., 2000; Fishman, Marx, Blumenfeld, Krajcik, & Soloway, 2004).

In this study we focus on the theory and process of designing quality project-based science curriculum materials to meet the needs of the larger reform effort.

Designing Materials for Urban Settings

Haberman (1991) put forth a set of recommendations for good teaching practices in urban schools to promote learning for all students. These include allowing students to solve problems that are of interest to them and to construct objects and perform experiments, reflect on real-life experiences, and access information through technology. Lynch (2000) and Atwater (2000) also recommend the systematic development of standards-based science curricula integrated with technology to address the inequalities that exist in urban classrooms and to narrow the achievement gap. One aspect of our larger collaborative partnership with Detroit's systemic reform effort through LeTUS has been to design curriculum materials that take into consideration these recommendations to address the needs of urban classrooms, using the framework of project-based science.

Project-based science (PBS) is an approach to teaching and learning rooted in inquiry pedagogy that is consistent with social constructivist ideas (Blumenfeld et al., 1991; Krajcik, Czerniak, & Berger, 2002). The presumption is that students need opportunities to construct knowledge by solving problems through asking and refining questions; designing and conducting investigations; gathering, analyzing, and interpreting information and data; drawing conclusions; and reporting findings. Fundamental to this perspective are the features of *active construction, situated cognition*, *community*, *discourse*, and *cognitive tools* (Novak & Krajcik, in press; Singer et al., 2000). Students' *active construction* of knowledge refers to engaging students with the task in thought-demanding ways such as explaining, gathering evidence, generalizing, representing, and applying ideas (Perkins, 1993). *Situated cognition* refers to students making meaning through interactions between the world and others, and their interpretations of these interactions (Lave & Wenger, 1991) within the contexts of the discipline. These interactions engage students with a *community* of practitioners in the discipline (Perkins, 1993) in which students learn ways of knowing, what counts as evidence, and how ideas are shared within the culture of the discipline. Participation also brings students into the language and *discourse* of the community of practice (Singer et al., 2000). *Cognitive tools* can extend what students can do and learn (Solomon & Perkins, 1989), in that they provide opportunities for students to visualize and explore phenomena that would not otherwise be possible in classrooms through manipulating multiple dynamic representations (Novak & Krajcik, in press).

The process of materials design and development in LeTUS is more than a typical curriculum intervention; it is an intensive collaborative undertaking by all partners and coordinated with the other aspects of the larger systemic reform initiative. Together with Detroit, LeTUS has developed five middle-school project-based science units: a sixth grade project on mechanical advantage; seventh grade projects on air quality, water quality, and communicable diseases; and an eighth grade project on force and motion (Marx et al., in press; Singer et al., 2000). Each project is built upon national and state standards, and as part of the collaboration with the Detroit Urban Systemic Program they explicitly support developing scientific understanding called for by the content and inquiry standards outlined by the Detroit school district. The curriculum projects are designed to last between 8 and 10 weeks. Learning is situated by contextualizing science instruction through the use of a driving question to introduce and structure the project. Driving questions are designed to be meaningful to students, to encompass worthwhile content, and to be anchored in a real-world problem (Rivet & Krajcik, 2002). Students engage in active construction of knowledge through investigations and artifact development that provide opportunities for them to learn concepts, apply information, and represent knowledge around the driving question. Learning technologies such as probes, dynamic simulations, and electronic resources are integral in the design of projects, serving as cognitive tools to extend what students can learn (Solomon & Perkins, 1989). Projects are designed to foster collaboration among students, teachers, and others in a community of learners and to promote discourse around the phenomena under exploration. Students' development of integrated understandings is further supported by providing multiple opportunities for them to experience, explain, and interpret phenomena within the exploration of the larger project setting.

The projects also include benchmark lessons that help students learn difficult concepts, illustrate important laboratory techniques, or develop investigation strategies (Krajcik et al., 2002). Furthermore, the curriculum materials for each project are designed to be "educative" for teachers (Ball & Cohen, 1996), helping to provide opportunities to learn about new teaching practices, content, and classroom enactment from the materials themselves (Schneider & Krajcik, 2000). Iterative revisions are made to the materials after each enactment informed by pre/posttest results, student and teacher interviews, and classroom observations (Linn & Hsi, 2000).

Principally, LeTUS project-based science curricula materials are designed to develop scientific understandings called for by district, state, and national standards for science education. National standards (AAAS, 1993; NRC, 1996) provide frameworks for curriculum to communicate the language of the disciplines and engage learners in the nature of science and practices of the scientific community. The AAAS and NRC documents specify the sequence and substance of science concepts, specialized language, and practices and methods for asking questions and solving problems. LeTUS curriculum materials build from these resources through embodying project-based science in a form usable by teachers in urban districts. The design of each project begins by first considering the individual science ideas, concepts, and phenomena as articulated in the standards and formulating learning goals to guide assessment of the standards. This is followed by the design and organization of activities, classroom structures, and curriculum materials needed to help teachers and students achieve these goals. It is an intensive, goal-oriented collaborative development process that builds from previous research in curriculum design (Cognition and Technology Group at Vanderbilt, 1997; Edelson, Gordin, & Pea, 1999; Linn & Hsi, 2000) and what is currently known about students' prior ideas and how best to address them (Driver, Squires, Rushworth, & Wood-Robinson, 1994; Novak & Gowin, 1984; Osborne & Freyberg, 1985) for the target science concepts. This process, which was followed for the development of each LeTUS unit, is illustrated through the following description of the development of the sixth grade project, *How Do Machines Help Me Build Big Things?*

Example: *How Do Machines Help Me Build Big Things?*

The sixth grade LeTUS project, *How Do Machines Help Me Build Big Things?* (Rivet & The Center for Highly Interactive Computing in Education, 2001), subsequently referred to as *Big Things*, is one example of project-based curriculum materials developed as part of the collaborative partnership between researchers at the University of Michigan and the Detroit Urban Systemic Program that fosters student understanding called for by local and national science standards. The contextualization of the project is framed by the driving question "How do machines help me build big things?" and is focused on learning about and developing a new machine to construct large buildings and bridges, an area identified as being of interest to young urban students (Seiler, 2001). Initially, students discuss large structures in Detroit, including the Ambassador Bridge, the Renaissance Center, and the new football stadium, Ford Field. The project is further contextualized as students take a walking tour of a local active construction site in the neighborhoods around their school and describe the different machines they see and how these machines function to help people build large buildings. Students use this anchoring experience (Cognition and Technology Group at Vanderbilt, 1992) to develop a design for a new machine of their own invention that can help to build large structures. Throughout the project students are asked to relate the concepts they are learning back to their new machine design. As such, this project combines both scientific inquiry and science of design approaches (i.e., Kolodner, Crismond, Gray, Holbrook, & Puntambekar, 1998). Students conduct investigations to explore scientific problems related to their real-world experiences with machines and construction, and use that information to inform the design of new machine of their invention.

The driving question is broken down into four subquestions that help to structure and organize this 8-week project (see Appendix A). The project builds from students' prior knowledge and everyday experiences about simple machines to explain scientifically how machines help us. During this project students develop an understanding of forces and the way balanced and unbalanced forces can affect the motion of objects, the functioning of simple machines, and the mechanical advantage provided by simple and complex machines. Learning technologies are used to support understanding of these concepts as students work with force probes to visualize the effects of balanced and unbalanced forces on the movement of objects, and relate this to their own machine's ability to push or lift heavy materials. Students investigate the principle of mechanical advantage, described as a trade-off between the amount of applied force and the distance that the force needs to be applied, in the functioning of three different simple machines (incline planes, levers, and pulleys). Students work in collaborative groups to design and conduct an extended investigation to explore how they might change a simple machine to increase its mechanical advantage. They apply and integrate their new knowledge gained in these investigations to the design of their own machine.

The project culminates with students creating a drawing or a working model of the new construction machine that they present to the class. The new inventions must meet several design criteria, including the use of at least three simple machines that work together. In addition, students write a description of the functioning of their new machine, including where the unbalanced forces are to move objects and the mechanical advantage of each simple machine and the overall complex machine. Student groups take part in a formal presentation of their new machine to the class, during which they demonstrate their understanding of the science concepts underlying the functioning of their new construction machine.

Building Understanding of Standards in *Big Things*

Big Things is designed to develop student understanding of several district, state, and national standards. These include both content-specific standards about science ideas and phenomena, as well as process-related standards, particularly with regard to conducting inquiry. The development process of this project began with consideration of the district and state science standards for sixth grade, which included the standard "design strategies for moving objects by the application of forces, including simple machines" (Michigan Department of Education, 2000). We identified three science concepts needed for students to understand this objective: balanced and unbalanced forces and their effect on motion; simple machines and how they work together in complex machines; and the concept of mechanical advantage. These ideas are articulated as part of the district and state objectives, as well as in national science education standards documents. The science concepts and inquiry skills were then articulated as learning goals for the project, which specified what students will be able to do to demonstrate their understanding of these ideas. Articulating learning outcomes in terms of performance makes explicit what we want students to learn (Reiser, Krajcik, Moje, & Marx, 2003). Table 1 displays the learning goals developed in this

Table 1
Science learning goals addressed by the Big Things project

Area:	**Balanced and Unbalanced Forces**
Learning goal:	*Students explain how objects are moved by the application of forces.*
Example standard:	NSES: If more than one force acts on an object along a straight line then the forces will reinforce or cancel each other, depending on their direction and magnitude. Unbalanced forces will causes changes in the speed or direction of an object's motion.
Opportunities to learn in *Big Things*:	• In order to address the driving question, students explore the subquestion, 'how do I move things?' They participate in a series of predict–observe–explain (POE) demonstrations to explore balanced and unbalanced forces and their effects on motion. • Using force probes, groups of students push and pull on a brick with different amounts of force. The force probes allow students to determine if the forces they apply on opposite sides of the brick are the same ("balanced") or different ("unbalanced"). Students relate these measurements to the motion of the brick across the table. • Friction and gravitational forces are also explored in similar POE demonstrations. • Through these experiences students develop the idea that their machine must apply an unbalanced force in order to move materials around a construction site. They describe this understanding in the final presentation of their new machine design.
Area:	**Simple and Complex Machines**
Learning goal:	*Students identify examples and uses of simple machines and describe how they change effort; students explain how the parts of complex machines such as simple mechanical devices work together.*
Example standard:	AAAS: Inspect, disassemble, and reassemble simple mechanical devices and describe what the various parts are for; estimate what the effect that making a change in one part of the system is likely to have on the system.
Opportunities to learn in *Big Things*:	• Students review the six simple machines with a focus on how the wedge and screw are variations of the inclined plane and the wheel and axle is a type of lever. They identify real-world examples of each machine. • Students describe the simple machines found in several complex machines, including both construction machines and smaller devices used everyday. They look at how these simple machines work together in order for the complex machine to function. • Students design a complex machine that utilizes two or more simple machines, and describe how these simple machines work together for their design to function.
Area:	**Mechanical Advantage**
Learning goal:	*Students analyze patterns of force and motion in the operation of simple and complex machines.*
Example standard:	Michigan Curriculum Framework: Analyze patters of force and motion in the operation of complex machines.
Opportunities to learn in *Big Things:*	• Students explore the subquestion 'How can machines move things that I can't?' through conducting a series of guided investigations that compare the amount of force needed to lift a brick straight up with their hands as compared to using a lever, inclined plane, and pulley. • In these investigations, students also compare the distance the force is applied through for each situation. They articulate mechanical advantage as the trade-off between force and distance when using a machine. • Students further explore this trade-off by designing their own investigation to study the mechanical advantage of different simple machines. • Students apply this understanding by describing the mechanical advantage of their new machine designs in the final presentation.

(*Continued*)

Table 1
(Continued)

Area:	**Inquiry Process Skills**
Learning goal:	*Students identify questions that can be answered through scientific investigations; students design and conduct simple investigations; students develop descriptions, explanations, and predictions using evidence.*
Example standard:	NSES: Design and conduct a scientific investigation; develop descriptions, explanations, predictions, and models using evidence.
Opportunities to learn in *Big Things:*	• Students make justified predictions and develop explanations based on their observations during the predict–observe–explain demonstrations about balanced and unbalanced forces. • In their guided investigations about mechanical advantage, students formulate hypotheses about the relationship between force and motion using simple machines. • Also in these investigations, students collect data using instruments (spring scales, force probes, meter sticks) and create comparative bar graphs of their force and distance data. They use these data as evidence to write their conclusions. • Students develop their own questions to investigate variations in a simple machine, design their own investigations to test their question, and develop conclusions supported by evidence from their data.

curriculum project, identified by area, and describes the opportunities for students to meet these goals in investigations, activities, and discussions throughout the unit. These learning goals build student understanding of several specific objectives called for in local and national science standards. Appendix B outlines the complete set of standards from the Detroit Public Schools Core Curriculum, the Michigan Curriculum Framework Science Benchmarks (Michigan Department of Education, 2000), the *National Science Education Standards* (NRC, 1996), and the *Benchmarks for Science Literacy* (AAAS, 1993) that are addressed in this project.

The next phase in the design process of *Big Things* was to consider possible contextualizing situations that would encompass these science concepts and allow students to relate the ideas to their real-world experiences. The driving question—"How do machines help me build big things?"—and the focus on construction sites within their city and local neighborhoods, was selected as the contextualizing theme. Activities, extended investigations, and support materials were then designed in coordination with Detroit teachers and district curriculum specialists to build student understanding of these learning goals for content and inquiry process skills and to develop the contextualizing theme. As can been seen in Table 1, the curriculum design of the *Big Things* project provides multiple opportunities for students to work with and develop understandings of the science learning goals. These learning opportunities were carefully selected and thoughtfully planned and organized throughout the extended project to leverage from the design features of project-based science and provide sequential and coherent experiences with the concepts.

The content and sequence of instruction was informed by previous research exploring students' prior ideas about each of the project's learning goals. For example, it is known that students commonly confuse force and mass (i.e., Eryilmaz, 2002), believe that forces belong to objects and reside in them (i.e., Driver et al., 1994; Heywood & Parker, 2001), fail to recognize that forces come in pairs, and cannot discern how unbalanced forces lead to a change in motion (i.e., Heywood & Parker, 2001). To address these common prior ideas, students explore the relationship between balanced and unbalanced forces and their effect on motion through a series of predict–observe–explain (POE) cycles (White & Gunstone, 1992) using a pair of force probes as they attempted to move a brick. Likewise, research has found that younger students do not have clear understandings of how simple machines work (i.e., Tucknott & Yore, 1999) and how force is transferred in a machine (Lehrer & Schauble, 1998). Lehrer & Schuable (1998) found that few middle school students were able to articulate or provide evidence for the relationship between the amount of force applied when pedaling a bike and the distance that the bike travels per stroke. These prior ideas were addressed through a series of investigations where students explored the relationship between the amount of force applied and the distance that the load travels by first using three different simple machines and then considering these machines working together in a complex machine. At the end of the project, students were asked to apply their knowledge of each of the project's learning goals to design a new machine that could build a large structure in their city. This final artifact served as an integration and transfer opportunity for students to demonstrate their understandings developed over the course of the project in the context of a new, yet familiar situation.

Throughout the development and iterative enactment of this project, lead teachers worked closely with university researchers to provide ideas, feedback, and field testing of the curriculum materials in development. At multiple points in the development process project materials were presented to the curriculum staff of the Detroit school district, who made recommendations for how these materials related to district standards. Participating teachers in the project received professional development support in the areas of science content, inquiry pedagogy, pedagogical content knowledge, and use of technology in classrooms, in the form of summer institutes, Saturday work sessions, and in-classroom support.

The *Big Things* project was enacted in the Detroit Public Schools four times from 1999 to 2001. With each successive enactment, greater numbers of schools, teachers, and students participated in the project. In addition, as participation increased, the leadership of professional development opportunities to support these enactments was transitioning from university researchers to district teacher leaders. We explored the usefulness of this project-based science curriculum in helping students develop understandings of the science learning goals and inquiry process skills through multiple measures, including classroom observations, student and teacher interviews, analysis of student work, and student learning gains through pre/posttest assessments. In this study we present the results of the pre/posttest assessment measure from the 4 years of enactment, and consider the results in light of the changes that occurred in participation and professional development of the *Big Things* project.

Methods

In this study we analyzed the learning gains of Detroit students who participated in *Big Things* during four enactments in terms of achievement outcomes on pre- and posttest measures. We also describe how the achievement results were used to inform modifications to the curriculum materials to better address the learning needs of Detroit students in this project.

Setting

During the 4 school years between 1999 and 2002, the *Big Things* project was completed by 24 teachers and over 2500 students at 15 different Detroit public middle schools located in lower socioeconomic-scale (SES) neighborhoods participating in the LeTUS reform effort (Krajcik, Marx, Blumenfeld, Soloway, & Fishman, 2000). Students in these schools are representative of the district, which is over 91% African American; 70% of students receive free or reduced-price lunches, and 85% of the statewide standardized eighth grade science assessment reports are below grade level (Detroit Public Schools, 2001). In total, 179 Detroit students participated in the *Big Things* project as part of their sixth grade science curricula during the fall 1999 semester, 299 students participated during the fall 2000 semester, 859 students participated during the fall 2001 semester, and 1239 students participated during the fall 2002 semester. Two teachers enacted the project during the fall 1999 semester. Both of these teachers had taught LeTUS projects before working with the *Big Things* project. During the Fall 2000 semester, these same two teachers plus two new teachers enacted the project. For one of the new teachers, this was her first time working with LeTUS curriculum materials. The second new teacher had previous experiences with LeTUS materials. During the Fall 2001 semester, a total of 11 teachers completed the *Big Things* project. Three of these teachers had previously worked with the *Big Things* materials. Of the other eight teachers, only one had previous experience working with LeTUS curriculum materials prior to *Big Things*. During the Fall 2002 semester, a total of 16 teachers completed *Big Things* in their classrooms. Seven of these teachers had used *Big Things* previously, and five others had experiences working with LeTUS curricula.

Teachers were provided multiple opportunities to participate in a variety of LeTUS professional development settings during each year of enactment, including a summer institute, Saturday workshops, after-school study groups, and one-on-one classroom instructional support (Fishman, Best, Foster, & Marx, 2000). The LeTUS summer institute was a 1-week workshop that engaged teachers with learning about inquiry teaching, new educational technologies, and fostering collaboration, as well as project-specific instruction that addressed the learning goals, contextualizing features, main activities, and assessments for each LeTUS curriculum project. Saturday workshops usually consisted of two parts. The first was project-specific group work where teachers focused on the specific content ideas and upcoming classroom events in their project enactments. The second was usually a cross-project session that delved further into specific aspects of project-based teaching. After-school study groups were opportunities for teachers to share and discuss what was going on in their classroom enactments of the project and allowed them to ask specific questions of other teachers or university researchers. One-on-one classroom support included planning and debriefing of individual lessons with a university researcher or district science coordinator, collaborative teaching, and support with classroom activities. As part of the systemic reform effort, leadership of these professional development opportunities transitioned from primarily university researcher-led sessions to experienced teacher-led sessions over the years of enactment. Table 2 displays the amount of each type of professional development available to teachers during each enactment of the *Big Things* project and the leadership of these opportunities. Of note is the fact that, during the fall 1999 enactment, the two participating teachers received almost daily one-on-one classroom support from university researchers, whereas, during the fall 2002 enactment, the 16 participating teachers received classroom visits from district science coordinators only three or four times over the course of the project, and no visits from university researchers. In addition, summer workshops and Saturday work sessions also transitioned from a university researcher-led to a solely teacher leader-led format during this time.

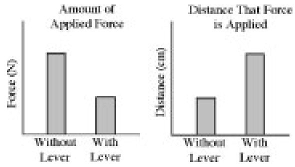
Data Collection

All students participating in the *Big Things* project were assessed by identical pre- and posttest measures before and at the conclusion of each enactment. The pre/posttest measures consisted of 18 multiple-choice items and 2 short response items, with a maximum possible score of 24 points. Table 3 displays each of the science learning goals addressed in *Big Things*, and example test items. Test items were created to measure both content and process understanding

Table 2
Professional development amount and leadership for each enactment

Type of Professional Development	One-on-One Classroom Support	After-School Study Groups	Saturday Workshops	Summer Institute
Fall 1999 (2 teachers)	• Almost daily • Led by researcher	• Four during project • Led by researcher	• Four during project • Led by researcher	• Two days • Led by researcher
Fall 2000 (4 teachers)	• Once a week • Led by researcher	• Four during project • Led by researcher and lead teachers	• Four during project • Led by researcher, lead teachers assist	• Three days • Led by researcher
Fall 2001 (12 teachers)	• Three or Four times during project • Led by researcher or district science coordinator	• Four during project • Led by lead teachers	• Four during project • Led by researcher and lead teachers	• Five days • Led by researcher and lead teachers
Fall 2002 (16 teachers)	• Two or Three times during project • Led by district science coordinator	• Three during project • Led by lead teachers and district science coordinator	• Four during project • Led by lead teachers and district science coordinator	• Five days • Led by lead teachers and district science coordinator

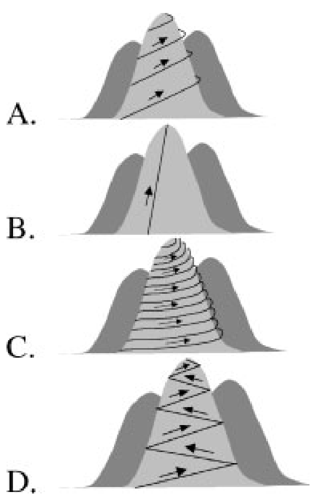
Table 3
Assessment items for Big Things

Learning Goal Area	Example Test Items
Balanced and unbalanced forces	*Low* Unbalanced forces can cause an object to do all of the following except: A. Start moving. B. Stay at rest. C. Slow down. D. Stop.
Simple and complex machines	*Medium* Tenisha wants to sew a new dress. In order to cut the fabric for her dress, she uses a pair of heavy fabric scissors. The scissors are a: A. Simple machine B. Simple machine made of an inclined plane C. Complex machine made of two levers and two wedges D. Complex machine made of a wedge and a wheel and axle
Mechanical advantage	*High (short response)* Explain why it is easier to use a screwdriver to open a can of paint instead of using just your fingers. Use the terms machine, force, and distance in your response. 
Inquiry process skills	*Medium* From these graphs you can tell that with a lever, the amount of applied force is _______________ but the distance that the force is applied is _______________ without a lever. A. Greater than, less than. B. Less than, greater than. C. The same as, greater than. D. Less than, the same as. 

across three cognitive levels—low, medium, and high. Low-level items involved the recall and comprehension of information. Medium-level items focused on drawing simple relationships, applying information to new situations, and translating between representations (i.e., between a data table and a graph). High-level items were all short-answer response items that asked students to create hypotheses, define and isolate variables, describe and analyze data, draw conclusions based on evidence, and use concepts to explain phenomena. The three levels of assessment reflect the goals of the project to develop students' science understanding at each of these cognitive levels. Three university researchers independently rated a subset of nine test questions as low, medium, or high cognitive level items. Agreement on the expert comparison of these items was 100%.

In addition, the pre/posttest assessed student understanding of the three science learning goals just described. A set of four to six test items, covering each of the three cognitive levels, were designed to assess each science learning goal of the curriculum. Items were similar in style and tone to those found on the state standardized achievement test as well as national assessments such those used by the Third International Mathematics and Science Study (Beaton et al., 1996). Table 4 displays an example of all test items addressing one of the science learning goals, that of mechanical advantage. The pre/posttest assessment also addressed student understanding of inquiry process skills, including conducting investigations, interpreting bar graphs, and writing conclusions supported by evidence. The whole test Cronbach alpha coefficient for the Fall 2002 posttest was calculated at 0.72.

Table 4
Test item cluster for the learning goal about mechanical advantage

Question Level	Test Item
Low	‘‘Mechanical advantage’’ is a term that means: A. The trade-off between force and distance when using a machine. B. Machines need more force to operate than other things. C. Machines are not better than people. D. The use of a powerful machine to move large objects
Low	Kevin wants to use a machine to apply less force when he moves a heavy box. Because of mechanical advantage, Kevin will also have to A. Apply the force through a smaller distance. B. Apply the force through a greater distance. C. Use more effort D. Use two machines
Medium	Alyssa is going to plant a new tree. She wants to dig the hole for the tree using less force. What is the best tool for Alyssa to use? A. A shovel with a long handle B.A shovel with a short handle C. A rake with a long handle D. A shovel with a bent handle
Medium	There are four paths up to the top of a mountain. Which one requires the MOST force to climb the mountain? 
High (short answer)	Explain why it is easiest to use a screwdriver to open a can of paint. Use the terms machine, force, and distance in your response. 

The pre/posttest assessment was intentionally designed with close proximity to the curriculum materials so the results could inform the design and support of the project itself. Thus, the assessment was presented to participating teachers as an evaluation tool for curriculum development, and teachers and students were not accountable for performance on this test. With each enactment, university researchers delivered the assessment and pretest student answer sheets to each teacher prior to the beginning of the project. Shortly after the pretest was completed, both student answer sheets and tests were collected from each teacher. At the conclusion of the project, new copies of the assessment and posttest student answer sheets were delivered to each classroom and the completed assessments were collected by university researchers. The student cover page for both the pre- and posttest assessment, which was read aloud by the teacher prior to students completing the test, explained that this test was a way for students to demonstrate their understanding of the concepts they learned (or were about to learn) in science class, to respond to each question the best they could, that their science grade would not be affected by how they did on this test, and that they had one class period to complete it. Teachers were given the opportunity to review their class results as a means to inform their teaching in a professional development setting.

Data Analysis

For the pre- and posttests administered for each enactment, correct responses were tallied on the multiple-choice items. Rubrics were created for open-ended items. Three university researchers scored a subset of student responses to each open-ended item using the rubric, and differences between scorers were discussed until a consensus on ratings was reached. This process was repeated until interrater reliability was established at 90% or better between scorers, and then the remainder of the open-ended items were scored using this rubric. The pre- and posttest data were organized and sorted to include only those students who had completed both the pre- and posttest for each enactment. Matched two-tailed *t*-test analyses were conducted to compare the pre- and posttest results after each year of the project enactment. The results of these analyses were used to compare overall gains, as well as gains for each of the science learning goals and cognitive levels, between enactments. These findings are considered in light of the changing contextual factors of the successive enactments, including greater numbers of students and teachers and the transition of the professional development leadership from university researchers to district and teacher leaders.

Findings

Assessment results are presented for Detroit students who participated in *Big Things* across four enactments. Overall, 24 teachers and over 2500 students participated in the enactments of the project in the Detroit Public Schools. In this discussion we also describe how learning gains from each year of enactment were used to inform modifications to the curriculum materials through an iterative revision process (Linn & Hsi, 2000) to better address the needs of Detroit students.

Pre- and Posttest Achievement

Matched two-tailed *t*-test analyses were used to compare the overall achievement gains between students' pretest and posttest. Table 5 presents pre- and posttest means, standard deviations, gain scores, and effect sizes for the overall results from each of the 4 years of enactment of the *Big Things* project. Effect size is reported here as a convenient standardized metric for evaluating the strength of student gains in large populations across varied student groups. The effect size indicates the average gain on the posttest measured in pretest standard deviation units. To aid interpretation, Cohen (1988) offered conventional definitions for the effect size (ES) as small (ES $= 0.2$), medium (ES $= 0.5$), and large (ES $= 0.8$). Effect sizes for total scores presented in what follows are all statistically significant ($p < 0.001$).

Table 5
Achievement outcomes for Big Things

	Students Matched Pre/Post (N)	No. of Teachers	Pretest Mean (SD)	Posttest Mean (SD)	Gain (SD)	Effect Size
Year 1 (1999)	179	2	9.78 (3.67)	14.78 (5.19)	5.00 (5.10)	1.36*
Year 2 (2000)	299	4	7.57 (3.36)	12.34 (3.99)	4.78 (3.64)	1.42*
Year 3 (2001)	859	11	6.88 (3.03)	11.31 (4.67)	4.44 (3.96)	1.46*
Year 4 (2002)	1239	16	7.05 (2.79)	11.54 (4.31)	4.49 (3.88)	1.61*

*$p < 0.001$.

Students consistently showed significant overall improvement on the pre/posttest measure for *Big Things* during the 4 years of enactment of the project. This finding is noteworthy considering that these results were achieved as use of the project increased to include more classrooms in the district and opportunities for intensive university-led professional development around this project decreased. The number of students participating in the project increased by 40% between the first and second years of enactment, by an additional 65% between the second and third years, and by an addition 30% between the third and fourth enactments. More teachers with fewer experiences using project-based materials were involved during successive enactments, whereas less classroom support from university researchers was available for new teachers (see Table 2). Even under these conditions of increased participation across enactments, the test scores indicate that students' science learning continued to occur successfully through involvement in the *Big Things* project.

In addition, scores for the four science learning goals addressed in the *Big Things* project were analyzed for the 4 years of enactment. The pre- and posttest means and standard deviations, gain scores, and effect sizes for each learning goal from each enactment are shown in Table 6. Figure 1 provides a graphic representation of the effect sizes for each learning goal. As can be seen in Table 6, significant gains were achieved consistently for all of the science learning goals throughout the years of enactment. Figure 1 shows the high effect sizes for student achievement in the area of mechanical advantage in each of the four enactments. Student achievement for this learning goal also increased with each successive year of enactment, from an effect size of 1.13 (fall 1999) to 1.32 (fall 2000) to 1.48 (fall 2001) to 1.51 (fall 2002). This learning goal was the focus of several investigations and activities in the *Big Things* project, as it was a means for students to integrate and apply their understandings of balanced and unbalanced forces and the functioning of simple machines. These test results are encouraging because this trade-off principle between force and distance when using a machine is not intuitive to students (Lehrer & Schauble, 1998) and it is a difficult topic to teach. In both the areas of balanced and unbalanced forces and inquiry process skills students achieved significant gains, although the calculated effect sizes decreased slightly for each of the first three enactments and rebounded slightly for the fourth enactment of *Big Things*. Student gains for the learning goal related to simple and complex machines showed consistently significant improvements for the first three enactments, yet dropping slightly during the fourth enactment. The test items in this area focused not only on identification of examples of simple and complex machines, but also on how the machines worked. These results highlight the ways that the project addresses students' limited prior understandings of how simple machines function (Tucknott & Yore, 1999).

From the fall 1999 to the fall 2001 enactments, several changes were made to the *Big Things* curriculum materials, which were informed by the results from previous enactments. Changes included shifting some investigations to have a stronger emphasis on mechanical advantage, and

Table 6
Achievement outcomes by science learning goal

	Pretest Mean (SD)	Posttest Mean (SD)	Gain (SD)	Effect Size
Year 1 (1999), N = 179				
Balanced/unbalanced forces (5)	2.11 (1.30)	3.26 (1.33)	1.15 (1.44)	0.88*
Simple/complex machines (4)	1.17 (0.95)	1.82 (1.13)	0.64 (1.31)	0.67*
Mechanical advantage (7)	3.75 (1.50)	5.44 (2.02)	1.69 (2.22)	1.13*
Inquiry process (8)	2.74 (1.55)	4.26 (2.35)	1.52 (2.35)	0.98*
Year 2 (2000), N = 299				
Balanced/unbalanced forces (5)	2.34 (1.36)	3.28 (1.39)	0.94 (1.54)	0.69*
Simple/complex machines (4)	1.12 (0.88)	1.79 (0.98)	0.67 (1.28)	0.76*
Mechanical advantage (7)	1.73 (1.28)	3.42 (1.70)	1.69 (1.68)	1.32*
Inquiry process (8)	2.37 (1.59)	3.85 (1.76)	1.48 (1.93)	0.93*
Year 3 (2001), N = 859				
Balanced/unbalanced forces (5)	1.75 (1.18)	2.47 (1.33)	0.72 (1.48)	0.61*
Simple/complex machines (4)	1.13 (0.95)	1.93 (1.11)	0.80 (1.37)	0.84*
Mechanical advantage (7)	1.40 (1.12)	3.06 (1.76)	1.66 (1.81)	1.48*
Inquiry process (8)	2.60 (1.69)	3.86 (2.10)	1.26 (2.07)	0.75*
Year 4 (2002), N = 1239				
Balanced/unbalanced forces (5)	1.48 (0.98)	2.19 (1.22)	0.71 (1.45)	0.72*
Simple/complex machines (4)	1.71 (1.07)	2.58 (1.05)	0.87 (1.31)	0.81*
Mechanical advantage (7)	1.37(1.00)	2.88 (1.49)	1.51 (1.67)	1.51*
Inquiry process (8)	2.49 (1.64)	3.89 (1.93)	1.40 (1.87)	0.85*

*$p < 0.001$.

providing assessment guidelines for students to explain the role of balanced and unbalanced forces in the workings of complex machines. In addition, supplemental student reading material was developed that addressed each of the science learning goals to accompany the curricular activities. The student readings were designed to connect with and support the project's learning objectives, the driving question, and the investigations and activities completed in class. They were designed using the idea of considerate text for young readers (Armbruster & Anderson, 1985), which entails using everyday language to make connections between students' experiences and new scientific concepts, presenting ideas in a logical and age-appropriate manner, and defining all technical and

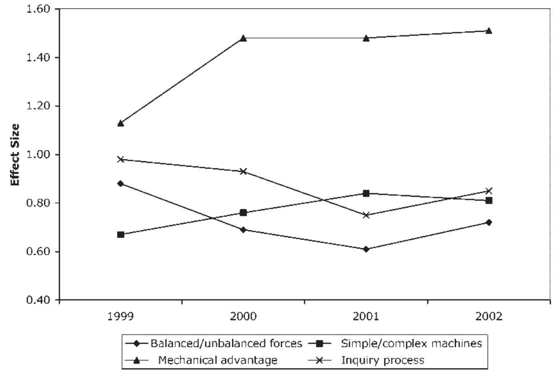


Figure 1. Effect sizes across enactments by learning goal area.

important terminology. The student readings were also designed to link to the reader's prior experiences, provide additional representations of the science concepts, and allow for opportunities to transfer and apply students' new ways of thinking about the content. These student readings were closely integrated with the existing curriculum materials to support their use in and as an extension of classroom instruction.

With these curriculum changes the achievement scores increased for the fall 2001 and fall 2002 enactments for each of the learning goals, particularly mechanical advantage. These gains coincided with an increase from 4 to 16 teachers working with the *Big Things* project in their classrooms. This finding indicates that the curriculum revisions appear to have addressed some of the needs of the teachers and students in these areas, even as the project participation increased to include greater numbers of teachers and students. In particular, we believe the introduction of the student reading materials as additional supports for learning may have been a contributing factor to offset the expected decrease in student achievement as participation in the project increased to include greater numbers of teachers and students.

In addition to looking at overall achievement scores for each of the science learning goals, analyses were conducted comparing the results on low, medium, and high cognitive level questions on the test. Table 7 presents the results of this analysis over the 4 years of project enactment. In this analysis, there is significant improvement for each of the three levels of questions, and this improvement is consistent across the 4 years of enactment. Across enactments, students overall scored better on the low cognitive level items than on the medium or high level items. An interesting finding is that the gains for the high cognitive level short response items improved substantially from the first to second enactment and continued to improve from the second to the third enactment. However, the scores for the fourth enactment on these items returned a level similar to that of the first enactment. We are not sure what the difference was between this last enactment and the previous ones that could account for this change. It may be a difference in the focus of the professional development opportunities offered by the lead teachers as opposed to the university researchers from previous years. It may also be an expected result as

Table 7
Achievement outcomes by question level

	Pretest Mean (SD)	Posttest Mean (SD)	Gain (SD)	Effect Size
Year 1 (1999), N = 179				
Low items (8)	2.26 (1.16)	3.74 (1.33)	1.48 (1.53)	1.26*
Medium items (10)	4.14 (1.77)	5.34 (1.86)	1.20 (2.20)	0.68*
High/open-ended (6)	0.71 (1.05)	1.58 (1.41)	0.87 (1.67)	0.83*
Year 2 (2000), N = 299				
Low items (8)	2.46 (1.51)	4.28 (1.64)	1.82 (1.86)	1.21*
Medium items (10)	3.96 (1.95)	5.34 (1.93)	1.38 (2.56)	0.71*
High/open-ended (6)	1.15 (1.27)	2.73 (1.72)	1.58 (1.74)	1.25*
Year 3 (2001), N = 859				
Low items (8)	2.24 (1.33)	4.20 (1.88)	1.96 (1.98)	1.47*
Medium items (10)	3.52 (1.77)	4.58 (2.01)	1.07 (2.10)	0.60*
High/open-ended (6)	1.12 (1.23)	2.53 (1.92)	1.41 (1.82)	1.15*
Year 4 (2002), N = 1239				
Low items (8)	2.62 (1.31)	4.82 (1.80)	2.21 (2.02)	1.68*
Medium items (10)	3.37 (1.62)	4.74 (2.10)	1.37 (2.26)	0.85*
High/open-ended (6)	1.06 (1.15)	1.98 (1.47)	0.92 (1.40)	0.80*

$^{*}p < 0.001$.

an increasing number of teachers and students participated in the project. This result indicates further consideration of the curriculum materials, professional development opportunities, and assessment methods used to explore students' high cognitive level thinking around these content and inquiry process ideas.

Discussion

In this study we attempted to demonstrate that, through designing science curriculum materials that build from district, state, and national standards and use a project-based science design model, as an integral part of a larger urban systemic reform initiative, students are able to develop understandings of science concepts called for by the standards. We found that the overall learning outcomes improved across the science learning goals and inquiry process of *Big Things*, even as participation in the project increased to include greater numbers of teachers and students. Students showed improvement in their understanding not only at a recall, descriptive level but also showed an increased ability to apply information to new situations and draw relationships between concepts. In addition, this approach to science instruction achieves these learning gains while also involving students in inquiry around real-world problems and utilizing new technology tools to support student investigations, instructional methods advocated by national reform documents (NRC, 1996).

It is particularly noteworthy that these learning outcomes were achieved at a time when the professional development support for the project was transitioning university researchers to district teacher leaders. Teacher and student participation in this project moved beyond a small classroom testbed model to include 24 teachers and over 2500 Detroit students (Fishman & Krajcik, 2003). Professional development during this time transitioned from primarily university research-led opportunities to more responsibility given to district curriculum support staff and teacher leaders. This scale of enactment provides more than simply proof-of-concept evidence for this project-based science unit, but rather indicates the potential of these materials to support a variety of urban science teachers and students in achieving local and national science standards.

In the analysis of learning outcomes of *Big Things*, there were several challenges that we identified. Although students showed statistically significant improvement consistently across the multiple enactments, the raw gain scores for each of the learning goals were not as high as we had anticipated. Although the test was intentionally designed to challenge students in order to avoid a ceiling effect, the gain scores indicated less overall improvement than we had hoped to achieve. This was particularly true for the high cognitive level short-answer items. We found that even on the posttest many students were leaving these items blank, or appeared to have much difficulty writing their responses to these items. We do not know if this is a result of the design of the test items, a lack of understanding of the science ideas being tested in the items, or difficulty in expressing their understanding through writing. Further research is needed in this area to inform both the supports offered in the curriculum materials for developing students' writing skills about science concepts as well as to inform the design of assessments to effectively tap students' scientific understandings.

It is also important to recognize that pre/posttest assessment is only one source of information about enactment of this project-based science unit in these urban classrooms. Consideration of observations, interviews, and student work can further inform a more complete picture of the successes and challenges facing teachers who work with this curriculum project. For example, classroom observations and teacher interviews have shown that teachers working with *Big Things* need additional supports for ongoing assessment in their classrooms and for building connections between this science content and other subject areas such as history and literacy in the curriculum materials. This information is also supported by analysis of the pre/posttest short response items, which indicate that students had difficulty writing answers to these questions. Further curricular and professional development supports in these areas may be one way to address this issue.

Critics of standards-based science reform have argued that these reforms ignore the interests and personal experiences of students (Seiler, 2001), compromise the professionalism of teachers (Settlage & Meadows, 2002), and are at odds with the prevailing cultures and practices of schooling (Tyack & Cuban, 1995), resulting in little impact on teaching practices and science learning occurring in urban classrooms such as Detroit (Blumenfeld et al., 2000). The findings presented in this study address many of the criticisms of standards-based instructional reforms. In our collaborative partnership with Detroit Public Schools, we have demonstrated our ability to develop curriculum projects that are usable and promote learning in urban settings as part of a sustained systemic reform agenda (Blumenfeld et al., 2000; Vinovskis, 1999). The project-based science unit presented herein appears to help students learn important science content called for by national and district standards in a way that is meaningful and engaging to students and promotes developing understanding and application of the ideas, not simply rote learning. The curricular materials are designed not simply to be implemented by teachers but rather to be educative. They also help teachers learn not only content but pedagogy skills and develop a better understanding of this inquiry-based approach (Schneider & Krajcik, 2000), which was indicated by the consistently high achievement even as more teachers participated in the project and leadership for professional development opportunities transitioned to district teacher leaders. The *Big Things* project provides an example to the educational reform community for a means to achieve science standards in urban environments, and can be used as a model for future curriculum development as part of science education reform.

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Appendix A:

Project overview for "How Do Machines Help Me Build Big Things?"

Learning Set	Topics Addressed	Process Skills
One: What are machines and how are they used?		
• Introduce driving question • Construction site walk • First new machine design	• Types of machines • Examples of machines	• Making observations
Two: How do I move things?		
• Student definitions of force • Force probe POE series • Class definition of force • Revisit new machine design	<u>Force</u> • Balanced and unbalanced <u>Motion</u> • Unbalanced forces result in motion of object	• Predicting, observing, explaining • Developing and sharing definitions

(*Continued*)

Appendix A:
(*Continued*)

Learning set	Topics addressed	Process skills
Three: How do machines move things that I can't?		
• Inclined plane investigation • Lever investigation • Pulley investigation • Revisit new machine design • Develop and conduct group investigations about mechanical advantage • Share results of investigations with class	Simple machines • Types and examples of each Mechanical advantage • The trade-off between force and distance when using a machine. Further exploring the trade-off in different settings related to using simple machines	• Collecting and graphing data • Interpreting comparative bar graphs • Drawing conclusions from graphs and using evidence to support conclusions • Asking good questions • Designing and conducting an investigation • Sharing results with others
Four: How can machines help me?		
• Complex machines • Develop new machine designs and prepare for presentations • Final group presentations	Complex machines • Simple machines working together in one device to accomplish a task	• Presenting design and information to others

Appendix B: Local, District, and National Standards Addressed in *Big Things*

Balanced and Unbalanced Forces

Detroit Public Schools Core Curriculum Outcomes

- Explain how objects can be moved by the application of forces (6.6).

Michigan Curriculum Framework Science Benchmarks

- Relate the motion of objects to unbalanced forces in two dimensions (M2).
- Design strategies for moving objects by means of the application of forces (M5).

National Science Education Standards

- If more than one force acts on an object along a straight line, then the forces will reinforce or cancel each other, depending on their direction and magnitude. Unbalanced forces will causes changes in the speed or direction of an object's motion (B).
- The position and motion of objects can be changed by pushing or pulling. The size of the change is related to the strength of the push or pull (B).

Benchmarks for Science Literacy

- The greater the force is, the greater the change in motion will be (4F).

Simple and Complex Machines

Detroit Public Schools Core Curriculum Outcomes

- Explain how objects can be moved by the use of simple machines (6.6).

Michigan Curriculum Framework Science Benchmarks

- Identify and use simple machines and describe how they change effort (E4).
- Manipulate simple mechanical devices and explain how their parts work together (E5).
- Design strategies for moving objects by the application of forces, including the use of simple machines (M5).

National Science Education Standards

- Evaluate completed technological designs or products (E).

Benchmarks for Science Literacy

- Tools are used to do things better or more easily and to do some things that could not otherwise be done at all (3A).
- Inspect, disassemble, and reassemble simple mechanical devices and describe what the various parts are for; estimate what the effect that making a change in one part of the system is likely to have on the system (12C).

Mechanical Advantage

Detroit Public Schools Core Curriculum Outcomes

- Explain how objects can be moved by the application of forces, including the use of simple machines (6.6).

Michigan Curriculum Framework Science Benchmarks

- Analyze patters of force and motion in the operation of complex machines (H1).

National Science Education Standards

- Design a solution or product, considering constraints and trade-offs, and communicate ideas with drawings and simple models (E).

Benchmarks for Science Literacy

- Technology extends the ability of people to change the world: to cut, shape, or put together materials; to move things from one place to another (3A).

Inquiry Process Skills

Detroit Public Schools Core Curriculum Outcomes

- Identify questions that can be answered through scientific investigations.
- Communicate scientific procedures and explanations.

Michigan Curriculum Framework Science Benchmarks

- Design and conduct simple investigations.
- Investigate toys/simple machines and explain how they work using instructions and appropriate safety precautions.

National Science Education Standards

- Identify questions that can be answered through scientific investigations (A).
- Design and conduct a scientific investigation (A).
- Use appropriate tools and techniques to gather, analyze, and interpret data (A).
- Develop descriptions, explanations, predictions, and models using evidence (A).
- Think critically and logically to make the relationships between evidence and explanations (A).
- Communicate scientific procedures and explanations (A).

Benchmarks for Science Literacy

- Find the mean and median of a set of data (12B).
- Organize information in simple tables and graphs and identify relationships they reveal (12D).

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