Iowa Science Teachers Journal

Volume 33 | Number 1 Article 4

2006

Rethinking the Rollercoaster: A Multi-Disciplinary Approach to Promoting Science Inquiry

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ABSTRACT: References to amusement park rides are often made when teaching students about motion and other physics concepts. The activity presented here goes further and engages students in using physics concepts, and extending this understanding to new concepts, including building roller coaster models that actually work. The value of the activity presented is its ability to promote several important goals for science learning, as well as describing the teachers' crucial role. *This article promotes National Science Education Content Standards A, E, F, and G and Iowa Teaching Standards 2, 3, 5, and 6.*

Introduction

Physics class has long been a source of hands on projects. From mousetrap cars to catapults, physics is the place where students explore the natural world using nifty toys. Students enjoy working with physics principles in an environment that encourages them to actually participate in a novel project. Of these, one of the most versatile projects that has become a classic for the physics curriculum is the roller coaster. Many students bring to physics class prior experiences riding all sorts of roller coasters and love to talk about their favorite thrilling curves, loops, twirls and twists.

Like any physics teacher, I wanted to capture this excitement and translate it into a constructive learning experience. As I looked for a roller coaster project to pursue, I was disappointed. Available roller coaster models were too rigid, allowing only one or two designs to be built. These projects were designed to reinforce concepts previously taught, not provide concrete exploratory experiences that students could use in scaffolding to abstract physics concepts. Moreover, because the success of the coaster activity relied primarily on following instructions, additional important qualities such as creativity, problem solving, critical thinking and other goals crucial for understanding science content and the nature of science went untapped. Finally, the coaster plans and lessons I observed failed to address the nature of science and engineering design, and reflected a very narrow view of physics.

Dissatisfied, I went about creating a more open-ended and mentally engaging approach to the coaster project. My vision was students working collaboratively like scientists, communicating, creatively and critically thinking, assessing their prior knowledge and accessing information in solving a genuine problem. I also sought ways to engage students across the curriculum by connecting their learning experience in physics to other subject areas.

I developed the following laboratory activity three years ago, and my experiences with it reflect the discussion of inquiry recently published appearing in the October 2005 issue of The Science Teacher. I also point to what McComas calls "challenge labs" (2005). He writes (p. 24), "challenge labs begin when I thought provoking question is provided to students in the briefest fashion possible." The challenge problem for this project is deceptively simple: design a functional roller coaster using simple materials. Beyond the initial challenge, students are then asked to build, test, and present a model of their coaster to a panel of observers. They must also submit a portfolio of written work in support of their coaster.

While this project typically requires two and a half weeks, the learning outcomes are substantial and worth the time and effort. Students are more engaged in thinking about and applying the science involved in their coaster. Students learn the value of working together in order to accomplish a shared goal. The collaborative nature of this project is important for teaching students how science and most other professionals work. Moreover, the extensive social interaction with peers and the teacher makes more likely that instruction will occur at a level that is optimal for each student (Moll, 1990). Students also engage in activities to strengthen information-gathering and processing skills, oral presentations, and planning and supporting arguments. They actually play the "game" of science (Yager, 1988), working out a solution to a novel problem, which enhances their critical thinking ability in terms of content knowledge (Knuth, et al., 1991). Covering less content in a deeper manner is at the heart of the National Science Education Standards (NRC, 1996), Project 2061 (AAAS, 1989), and all other reform documents. Engaging students more deeply in fundamental science content so that they actually learn and can apply it is far better than covering more information that students never truly understand and soon forget.

The Assignment

In creating a working model roller coaster, the coaster must be functional and use a 2.5-cm diameter steel ball as the car. I choose to offer steel balls rather than cars because of the increased engineering challenge of keeping the ball on the track. Similarly, this low-tech option creates more impetus for creative problem solving as students struggle to mimic ride features from real coasters. For the track, I provide hot wheels tracks, though students usually incorporate other surfaces and materials. Students simultaneously work on tasks that must be completed for their oral presentation and written portfolio. The portfolio consists of the following:

- a ▸ a written paper describing their coaster design;
- b ▸ a clear explanation of the physics concepts behind a real roller coaster of their choice;
- c ▸ test data from their coaster including time and distance measurements from the coaster, broken down into small segments;
- d ▸ an advertisement for their coaster in both English and a foreign language of their choice;
- e ▸ scale drawings of their coasters from multiple views, as well as calculations to scale their coaster up to a real coaster of maximum height of 100-meters;
- f ▸ a memo describing team function and problem solving methods employed by the group; and
- g ▸ a written self evaluation from each team member discussing personal performance for the project.

The oral presentation places the team in the role of an engineering design company selling their coaster idea to a group of investors. The teams answer questions about how their ideas could be translated to real life, their vision behind the coaster design, and structural questions of how to make the coaster safe for consumers. Students use information from their portfolios, research, and personal ideas to promote their design.

Background Knowledge

I purposely choose to implement this project immediately following our unit on velocity. At this point, my students must use what they know about kinematics to graph position versus time for the coaster and use that information to calculate velocity. In this sense, the coaster project serves as an application activity that assesses and bolsters their understanding of physics content already taught. However, the coaster project also serves as a wonderful concrete inquiry experience to now use in teaching new physics concepts. For example, after completing the project, students will refer back to both the scale drawings and test measurements to approximate other quantities such as acceleration, frictional losses, and kinetic and potential energies. Through carefully guided discussions I have students consult their data tables created for the coaster project to search for patterns in velocity change. With carefully crafted questions the coaster project and ensuing discussions aid in developing the conceptual basis for acceleration.

For my students the coaster project comes early in the school year, but it could be implemented at almost any stage of learning within Newtonian motion. By adjusting measured data to fit the level of learning the project could serve any number of conceptual points within the typical physics curriculum. Indeed this project, with its broad scope and cross-curricular emphasis, could serve nicely as a final project to summarize learning throughout the year.

Getting to Work

Students, grouped in two to four member teams are given two full weeks in the lab in order to design and test their coasters. Other assignments are pursued outside of class time and within other courses. Because the coaster project demands more than any one student can accomplish alone, it provides an excellent experience for teaching about collaboration. Learning how to work as a team reflects how science is done and what most future careers will demand. Students often split jobs among themselves and thus feel positive interdependence with other team members. This then resurfaces in the oral presentation, as team members step forward to speak about their areas of expertise. In terms of the scaling of their model, I provide no size requirements for coasters other than they must fit into the room we're building and not impede other teams. Coaster scales are generally large enough to incorporate design ideas from all team members.

Since students are assessed on creativity, I hold a class discussion regarding what constitutes a creative roller coaster. Invariably students look for uniqueness and interesting features, but I am often surprised by their thoughtfulness. This year, one student suggested that more “dangerous stunts” should garner higher creativity scores, but only if the teams could rationalize the safety precautions that would allow the coaster to work in the real world. Another suggested that the coaster needed to maintain “great speed” through the course of the ride, which launched the class into a discussion about whether the ride needed to be fast throughout, or vary in speed; a definition for the term “great” was also negotiated.

After the design ideas are in place, teams begin to lay and test their track. Testing becomes a challenge as students place braces and barriers to keep balls on the track; others work to perfect a specific design idea such as a twist or snaking corners. After a lot of tweaking, and large amounts of duct tape, teams are ready to begin timing individual segments of the track.

Crossing Over

As students tackle this multifaceted project, several other disciplines are incorporated. Through written papers, composition and research skills are engaged. Students often consult with the industrial arts teacher to work with AutoCAD systems to produce scale drawings. Design principles and art are incorporated when students create their coaster advertisements, as are media literacy and the use of foreign language. Naturally, mathematics, science, and engineering are seen by students to have much broader range than is commonly thought, providing an excellent opportunity for teachers to engage in discussion of the nature of science, science as a human endeavor, and confront stereotypes of scientists. Though not necessary for the activity, many of our teachers in the above content areas get involved with teaching in their subjects crossed with physics.

Evaluation

When presentation day comes around, teams are nervous. Other teachers, administrators, and community members are invited to come and act as investors, to listen to and question the teams. This year we even had an entire seventh grade class visit, giving us a wonderful opportunity to show off our knowledge and encourage younger students to further their science education. Far too few students in our country complete a physics course, and this coaster project is one of many experiences I use to attract future students.

Teams bring their portfolios to the presentation and begin to pitch their ideas, culminating with a demonstration of their coaster. After teams present their ideas, they take questions from the potential investors. Since the question and answer sessions are unscripted, students must think on their feet to address questions about how to make their ride safe, where their ideas originated, and how they might change their ride to incorporate more current roller coaster technology. The investors assess for creativity and presentation style, having been supplied with the criteria determined by the class.

Prior to receiving external feedback, teams must self-evaluate their effort, performance, and where work is needed. Accurate self-assessment is a crucial skill, as introspection provides more insight into personal effort, understanding, and performance than outside grading. As students continue their formal education and later take on more responsibilities in their careers and personal lives, the ability to accurately self-assess will prove invaluable for determining and improving what they do. The self-assessments come in with a letter grade depicting what the student feels he or she earned, along with an in depth defense of this grade.

When I first implemented this, I suspected that students would simply give themselves an "A", as the self-assessment counts as ten percent of their overall grade. However, I have found that when students have criteria that they understand and accept as reasonable, and are helped to apply those standards, they are quite candid and accurate in their self-assessment. Students will accurately judge their personal performance (even at the "C" and "D" level) and exhibit thoughtfulness in looking at the positives and negatives of their performance. By giving them a chance to discuss their own work, the students took a much more careful and critical view of themselves.

The Role of the Teacher

The coaster project sets a stage for promoting student learning of physics concepts and achieving other equally important goals, but how teachers implement the activity and work with students will determine the extent that these goals are actually promoted. This project relies heavily on the use of several teacher strategies to enhance student thinking and learning. While the project could be done as a directed cookbook activity, that approach would not promote a deep understanding of physics concepts, critical and creative thinking, problem solving, communication and collaborative abilities, self-evaluation, and other attributes of a well-educated and scientifically literate person. However, if students are doing more than simply following directions, the teachers' role becomes crucial in helping students make connections, assess their work, and make appropriate changes. This requires attention to:

- *Teacher Behaviors*. Asking open-ended questions throughout this project helps the teacher determine what students are thinking. This information is crucial in asking further questions that help students see problems in their thinking and make desired connections. Questions such as, "What are some ways that you might keep the ball from falling off the track at that point?", "What sort of vision are you trying for with this stunt?", and "How might you use what you learned about velocity in solving this problem?" encourages students to think deeply about their work and related physics concepts.

Asking thought provoking questions, especially in situations when students ask questions about how to get a particular segment of the coaster to work, encourages students to think through their problems rather than simply looking to the teacher to solve their dilemmas. Wait time I and II are a must to provide time for students to think and express that thinking. Both encouraging non-verbal behaviors and using students' ideas (whether they are right or wrong) are important for creating a positive environment where students feel comfortable expressing ideas they are not yet certain are correct. The culmination of these teacher behaviors promotes student thinking and provides the teacher a window into their thinking.

- *Understanding the Nature of Science*. This project provides several opportunities for teachers to explicitly raise important issues about the nature of science. While working and testing solutions, the teacher should engage students in discussions about the implications of having to test and retest ideas, about the role of creativity in science, and about science as a collaborative effort among men and women. As students approach problems and solutions in varying ways, the teacher raises the issue of no single, universal method for doing science, instead focusing students on scientific principles of developing knowledge. All of these discussions can take place while students continue to work on their projects.

- *Assist rather than dictate*. During this project the teacher's overall role is to help students make connections and learn from their mistakes, not make decisions for them, as this is not how people learn (Bransfor et al., 2000). Students should be encouraged to take safe cognitive risks, attempt as many ideas as they can muster, and present reasons for their decisions. This promotes deep cognitive reflection and places students reasoning and understanding at the center of classroom activities. This approach also better reflects the nature of science as scientists must work with peers to determine the veracity of proposed ideas. Some mistakenly see this approach as simply handing over to students all responsibility for learning. This is not the case! As Clough (2002, p. 93) writes:

> Both the student and teacher are thinking, but at different planes. The most significant difference is that while students are connecting these hands-on experiences to their current and emerging conceptual framework, the teacher is desperately trying to understand students thinking to further engage them in that construction of knowledge. Hence, placing greater responsibility on students does not mean simply having them figure things out on their own. Rather than abdicating responsibility for teaching, an understanding of how people learn demands from teachers a far more complex and demanding role in promoting students understanding of science.

Conclusion

The teacher makes the difference in whether this project will or will not promote deep understanding of physics and other equally important goals for students. The teacher behaviors explained above used in conjunction with class discussions about the physics content and the nature of science is what makes this a project that students will remember for not just the enjoyment of working with roller coasters, but also for the teamwork and learning that occurred in creating them. understands about student learning and effective teaching.

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