September 2004

Reflection on learning about forces

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Force is a basic concept in the physical sciences. It is included in Pakistan's national curriculum from the primary level through the higher levels. Because of the abstract nature of the concept of force, both students and teachers have alternative frameworks in this area. This was revealed in our classroom discussions on force during the Lower Secondary Science Module of the M.Ed. program at the Aga Khan University Institute for Educational Development (AKU-IED) in Karachi, Pakistan.

In-depth discussions and a variety of activities we carried out while teaching about forces challenged our previous concepts and allowed us to think critically about the teaching and learning of forces. In this article, we reflect on our teaching and learning experiences and possible ways, in light of our new learning, to make the concept of force understandable to students.

Rationale

The module made us realize that our understanding of the concept of force was linear (that is, not applicable in diverse situations) and that in some cases we held alternative frameworks. The detailed discussions and experiments helped us rectify our alternative frameworks. Also, because of our lack of content knowledge and pedagogical skills, we had difficulty designing activities and clarifying the concept of force for our students. The module's emphasis on activity-based teaching rather than lecture-based teaching prompted us to write this article about our experiences and learning at the AKU-IED. Writing this article has prepared us to teach about forces more dynamically. We also wrote the article to develop a critical stance toward our practical experiences at the AKU-IED and their implications for the classroom, to develop an approach using prediction and observation in the classroom for students' conceptual understanding, to explore how to help students understand the concept of force using simple materials and, finally, to reconstruct our learning and reflect on our previous understanding of forces.

Previous Teaching and Understanding of Forces

Science is a human activity, and its teaching should be related to real-life situations. In Chitral, a remote mountainous district of Pakistan's North-West Frontier Province, teachers teach science without relating it to daily life. They give students only the textbook definitions of scientific concepts for memorization. This approach, we have come to believe, does not help students develop conceptual understanding. Before coming to the AKU-IED, we taught in a similar way.

We used to teach the concept of force the way we were taught. In the physics textbook for 15- and 16-year-old students, *force* is defined as "an agent which moves or tends to move a stationary object or stops or tends to stop a moving object." That is what we taught our students. For further explanation, we used only the examples in the textbook. Thus, our teaching of forces was limited to the textbook. This is why our students' conceptual learning did not expand. We also taught the concepts of magnetic and gravitational forces but did not use hands-on activities or relate the concepts to real-life experiences. The categorization of forces into contact forces and noncontact forces was also not clear to us, which is why our students could not differentiate between the two and had alternative frameworks. Tobias (quoted by Stepans 1996, 4) states, "Science is made difficult by the way it is presented in textbooks and in classrooms." Teachers do not try to explain the concepts beyond the textbook, and sometimes textbooks are the source of alternative frameworks. In fact, Riche (2000) declares that textbooks are the most significant source of alternative frameworks in the physics classroom. Prior to our AKU-IED experience, we did not think of analyzing the textbook definitions or exploring students' prior knowledge about forces before introducing the concept.

In everyday language, the word *force* is used in a variety of contexts and has many meanings (for example, *force of argument, military force* and *task force*). In science, *force* has a technical meaning at variance with its common meanings. Students come to school knowing the everyday meaning of *force,* which is difficult to change when they come across the scientific concept of force. Riche (2000) notes that perceptions of the natural world are popular conceptions rooted in everyday experience; therefore, they influence the learning of new ideas.

The concepts of force and motion are vague, complex and abstract. According to Gunstone and Watts (1985, 89), "the concept of force itself has quite a curious history. Even comparatively recently the concept was vague and not clearly isolated in science." Scientists such as Aristotle, Buridan and Newton tried to explain the concepts of force and motion. The current theories of force and motion are based on Newtonian theory. Gunstone and Watts hold that Newton's conceptions of force possess some old beliefs such as inertia being an internal force rather than an external, applied force that changes the velocity of moving objects. Many people continue to believe in the old conceptions of force and motion. Thus, it is not surprising that schoolchildren of today hold the conceptions that were considered correct by most people, even scientists, in ancient times. Teachers should acknowledge this tendency and then use scaffolding to teach students in an easy, comprehensible way.

Here, we share two alternative frameworks that we had prior to the AKU-IED science module and that, without knowing, we taught to our students. The literature reveals that teachers in other countries also hold these alternative frameworks. The first alternative framework is the idea that if a body is moving, a force is acting on it (Kruger, Palacio and Summers 1991; Gunstone and Watts 1985; Palmer 1998). The second is the idea that "if an object is at rest (like a book on a table) then no forces are acting on it" (Driver 1983).

These alternative frameworks are based on the daily experiences of learners. It would make no sense to the students if the teacher told them that two forces are acting on a book resting on a table and that the two forces are equal in magnitude but opposite in direction and, therefore, cancel each other's effect, causing the book to remain stationary. Although we had textbook knowledge of this concept, because of our lack of pedagogical content knowledge, we never considered the difficulties our students might have in grasping the concept.

Similarly, most students believe that a heavier object will reach the ground faster than a lighter object when the objects are dropped simultaneously. The scientifically accepted idea is that the objects will hit the ground at the same time in the absence of air resistance. This, as we learned during the module, can be explained by Newton's second law of motion ($F_{net} = ma$) and the concept of the weight of the object. We further tested the idea through a simple activity: dropping a coin and a stiff paper disc of the same size from the same height. The coin hit the ground first. Next, we put the paper disc on top of the coin and dropped the assembly. The coin and the paper disc reached the ground at the same time. Unless teachers engage students in appropriate activities and discussion, the students will find it difficult to understand the idea that heavy and light objects hit the ground at the same time.

Students also have difficulty accepting friction and gravity as forces, because we do not consider them to be so in daily life. Bushell (2000) points out that one cannot literally see gravity and friction. For instance, when something falls to the ground, a child does not see the presence of gravitational force. Similarly, when a moving ball slows down, a child does not assume that it is because of the existence of frictional force. Once again, appropriate activities followed by discussion help students develop understanding of these phenomena.

How to Deal with Students' Alternative Frameworks

Teachers must recognize students' alternative frameworks and bring them to the surface. However, teachers should be aware of their own alternative frameworks before exploring those of students.

After analyzing the information obtained by eliciting students' ideas, teachers can design activities that challenge the alternative frameworks. Gunstone and Watts (1985) suggest that giving students opportunities to elaborate their viewpoints, challenging those viewpoints and discussing the resulting conflict between ideas help students learn the new ideas. Conceptual conflict serves as strong motivation for further learning. Gunstone and Watts further propose that the "new view must be intelligible, plausible and fruitful" (p. 100).

During the module, we learned the strategy of predict–observe–explain (POE) and realized that POE is an effective way of developing students' conceptual understanding. In fact, discussion is at the heart of the learning process. Discussion helps students clarify their alternative frameworks and enhance their understanding. Teachers should pose thought-provoking questions to make discussion meaningful for students.

We also learned that illustrating forces through free-body diagrams with arrows is a useful strategy. For example, the forces acting on an object at rest can be represented by arrows. We knew that force is a vector quantity and that arrows can represent it, but the idea that arrows can also represent the magnitude of force was new to us.

From classroom discussion, we learned that using an analogy between a known concept and an unknown concept can help students learn new information and discard or modify alternative frameworks. Clement (1987) suggests using anchoring conceptions and bridging analogy, where the targeted problem presented is analogous to a commonly understood physical phenomenon. For example, to convince students that a table exerts upward force on a book lying on it, Clement suggests using the analogy of force exerted by a spring on a hand that is compressing it. This bridging analogy helps students to imagine the force exerted by the table on the book. Similarly, a teacher can use an analogy to give students the idea that pull is experienced not only by objects, such as a falling ball, but also by Earth. The difference is that Earth, being massive, does not move like the ball does. The teacher can attach two table-tennis balls to a rubber band, place the arrangement on a table, pull the balls apart and let them go. Both balls move and collide midway. Next, the teacher can try the same thing with a table-tennis ball and a soccer ball. The soccer ball does not move, but the table-tennis ball does. The soccer ball represents the Earth and the table-tennis ball represents an object in Earth's field. Teachers must be careful to avoid giving students further alternative frameworks when using analogies and metaphors. For example, the analogy uses rubber bands, but in actual Earth–object systems, there are no such concrete materials connecting the Earth and the object.

Novak and Gowin (1984) recommend helping students "learn how to learn," which is called metacognition. Metacognition helps students to be conscious of and monitor their own learning to enhance it.

Implications

The findings of this inquiry have the following implications for teachers and teacher educators:

- Exploring students' preconceptions and using them as a starting point helps in developing their conceptual understanding.
- Students have different learning styles and interests; therefore, using a variety of teaching strategies and activities involving simple materials such as charts, pictures, drawings, free-body diagrams and careful use of analogies helps clarify the concept of force.
- Using simple language and consistent scientific terminology according to the level of the students is helpful.
- Holding a discussion based on POE and problem solving helps clarify the concept of force.
- Teachers should be aware of the common alternative frameworks held by students about the concepts of force and motion.

Conclusion

The concept of force is complex and, therefore, challenging to teach in the classroom. Students, and even adults, hold alternative frameworks in this area. The ultimate responsibility of teachers is to provide opportunities for students to rectify their alternative conceptions and gain conceptual understanding by using anchoring examples and bridging analogies. POE and hands-on activities play important roles in constructing students' conceptual understanding.

Teachers must examine and rectify their own conceptual understanding so that they can present clear concepts to students. The concept of force should not be presented as just a rote-memory item. Pedagogy and content knowledge should be integrated so that teachers can address students' alternative frameworks and design teaching accordingly.

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Mir Zaman Shah, Mahmood Ghaznavi and Mohammad Ibrahim Khan gratefully acknowledge Harcharan Pardhan for her encouragement and support and the Aga Khan University Institute for Educational Development for providing this research opportunity to them.