TAKING FIRST STEPS TO UNDERSTAND TRANSFER OF SCIENTIFIC ABILITIES

This study investigates internalization and transfer of scientific abilities by students enrolled in an introductory physics course at a North Eastern state university The abilities include designing investigations to test hypotheses, representing ideas in multiple ways, and communicating these ideas.

Eugenia Etkina, Rutgers University, Graduate School of Education
Sahana Murthy, Rutgers University, Graduate School of Education

Introduction

Hundreds of thousands of science and engineering students take introductory physics courses each year. These courses are expected to promote scientific literacy, critical thinking skills and help students develop abilities necessary for the 21st century workplace. Studies from different sources (NSF, 1996; Bransford, Brown, & Cocking, 1999; Czujko, 1997) agree that the workplace needs graduates who develop science process abilities, such as the ability to pose a question, to design an experiment to test a hypothesis or to solve a problem, to collect and analyze real data, and to communicate the details of the experimental procedure. Most science education programs do not adequately foster these abilities in students (Barab & Hay, 2001).

The goal of this study is to investigate whether inquiry based laboratories, which are integrated into an introductory physics course taught via the Investigative Science Learning Environment *(ISLE)* approach (Etkina & Van Heuvelen, 2001) promote transfer of some scientific abilities (Etkina, 2004). We use the term *scientific abilities* instead of science process skills to emphasize that these are processes we would like students to use reflectively, similar to those that scientists use in constructing knowledge.

Theoretical underpinnings

If we agree that the development of scientific abilities is an important goal of science instruction, we need to determine whether they are transferable. Transfer refers to the ability to apply knowledge, skills and representations to new contexts and problems (Barnett & Ceci, 2002; Bransford, Brown & Cocking, 1999; Detterman, 1993; Larkin, 1989; Mestre, 2002; Salomon & Perkins, 1989). Research shows that achieving transfer is difficult (Gick & Holyoak, 1983) and requires that knowledge be applied in different situations (Spiro Feltovich, Jacobson & Coulson, 1992). There are several theoretical models of transfer, and in the proposed study we will address Direct Application model which considers “the ability to directly apply one’s previous learning to a new setting or problem” (Bransford and Schwartz, 1999). Transfer can be near or far. When a situation in which a person needs to apply knowledge or skills is close to the situation in which she learned the knowledge or skills, the transfer is near. If the content or context is different, or the new task is given much later than the training task(s), the transfer is far. A rigorous classification of the work on transfer is presented in Barnett & Ceci (2002).

A variety of factors affect transfer. The first is the need for the acquisition of deep and meaningful knowledge (Klahr & Carver, 1988). The second is a person’s previous knowledge, which may positively affect transfer, but can also impede it (Bransford, Brown & Cocking, 1999). Finally, the context in which the knowledge has been learned determines the degree of transfer to a particular novel situation (Catrambone & Holyoak, 1989; Mestre, 2002). To facilitate transfer, instructors may focus students' attention on pattern recognition among cases and induction of general schemas from a diversity of problems (Gentner, Lowenstein, & Thompson, 2003). Another strategy is to engage students in meta-cognitive reflection on implemented strategies (Salomon and Perkins, 1989) with sufficient abstraction from the content of the task (Larkin, 1989). Formative assessment and self-assessment increase the depth of understanding (Black and Wiliam, 1998) which enhances the probability of transfer.

ISLE learning system

The Investigative Science Learning Environment replicates some of the processes that scientists use to construct knowledge. Students start each conceptual unit by analyzing patterns in experimental data to construct possible explanations or mathematical relationships. They learn to represent their ideas in multiple ways using diagrams, graphs, bar charts and so on. In the next and crucial step, students test their constructed ideas by using them to predict the outcomes of new experiments, and possibly revising their ideas if the outcomes do not match the predictions. Finally, students apply these ideas to solve problems experimentally. Many steps in the above cycle are performed in labs. ISLE labs are open-ended and have a non-cookbook format. Students work in groups to design their own experiments. Write-ups for *ISLE* labs do not contain instructions on how to perform the experiments but instead guide students through various aspects of a typical experimental process as shown in the example below. Students' use self-assessment rubrics that scaffold their work on experiments and help them write lab reports. The rubrics contain descriptors for individual scientific abilities and promote self-reflection.

The *ISLE* approach combined with formative assessment tasks and rubrics has many elements that have shown to promote transfer. Thus we hypothesize that students who learn physics through ISLE and use scientific ability rubrics to self-assess their work should not only acquire scientific abilities but also be able to transfer them. This hypothesis is based on the assumptions that students acquire deep understanding of physics and of the abilities, can recognize patterns in laboratory tasks with the help of rubrics, abstract the abilities from the tasks, and map these patterns into new situations. To test whether students transfer some of the abilities acquired in the labs we conducted the study described below.

Description of the study

The study was conducted in a large enrollment (190 students) introductory two-semester physics course for science majors. There were two 55-min lectures, one 80-min recitation and a 3-hour lab per week. In each semester students performed 10 labs and had 2 lab practical exams. A lab usually contained two design experiments. Write-ups for the experiments resembled the example shown below. During each lab students used self-assessment rubrics to structure and improve their work (the rubrics are available at http://paer.rutgers.edu/scientificabilities).

In the week 2 of the first semester, students had to design an experiment to test a proposed rule [in the case below students were given an incorrect rule]. The write-up for the experiment is shown below.

Design an experiment to test the following rule: An object always moves in the direction of the unbalanced force exerted on it by other objects.

a) State what rule you will test in your experiment.
b) Brainstorm the task. Make a list of possible experiments. Decide what experiments are best.
c) Draw a labeled sketch your chosen experiment.
d) Write a brief description of your procedure.
e) Construct a free body diagram of the object.
f) List assumptions you make. How could they affect the prediction?
g) Make a *prediction* about the outcome of the experiment *based on the rule you are testing*.
h) Perform the experiment. Record the outcome.
i) Make a judgment about the rule based on your prediction and the experimental outcome.

During the final exam (week 14 of the semester), one of the 30 questions that students had to answer was as follows. Describe an experiment that you could design to test the following rule: An object always moves in the direction of the unbalanced force exerted on it by other objects. This question is almost identical to the lab experiment, however, there were no guidelines (parts a)-i) above). According to the classification of transfer by Barnet and Ceci, the transfer we were examining was near in terms of knowledge domain but far in terms of physical context (exam hall instead of a physics lab), functional context (writing an answer to a question versus designing and performing an experiment), social context (individual versus group), modality (exam versus a lab), and temporal context (the exam was 3 months after the lab).

Findings

We read students responses and recorded the numbers of students who exhibited the acquisition of the following scientific abilities: the ability to design an experiment to test a hypothesis, the ability to make a prediction of the outcome of the experiment based on the proposed hypothesis, the ability to consider assumptions inherent in the experimental procedure, the ability to communicate the details of the experimental procedure and the reasoning process. The details of the findings are presented in table 1.

Table 1. Data from final exam question. (N= 181)

Scientific ability that students demonstrated	Number (percent) of students
Designed experiment to try to reject rule	104 (58%)
Designed experiment to try to support rule	73 (40.5%)
Recorded possible assumptions in the experiment	85 (47%)
Made a prediction based on rule to be tested and effect of assumptions	28 (16%)
Made a prediction based on rule without considering effects of assumptions	115 (64%)
Used previous knowledge not the proposed rule to make prediction	58 (32%)
Drew pictures	169 (94%)
Drew physical representations (Free body diagrams, motions diagrams)	81 (45%)

Discussion

We found that a significant number of students applied scientific abilities emphasized in the course and especially the labs. Studies of transfer demonstrate that about 20% of the subjects transfer a desired skill without a hint (Gick & Holyoak, 1983). In our experiment we found some larger numbers. Could it be that students remembered the content of the task from 3 months ago?

We speculate that it is unlikely that students remembered the details of the lab write-ups from of the first labs. Could it be that students knew the content very well and thus could focus on the scientific abilities well? We analyzed a multiple-choice problem involving the similar content on the exam and found that only 45% of students obtained the right answer. Could it be that only the best students could transfer the abilities? The correlation coefficient between the scores on this problem and the total exam score is 0.34, which is statistically significant (at the 0.01 level), but is still rather small to explain the variance. Thus we conclude that students did in fact transfer some of the scientific abilities learned in the course, mainly the ability to communicate the details of the procedure, the ability to represent information in multiple ways and the ability to design an experiment to disprove a proposed rule. We speculate that the reasons for the success were repetitive attention to these aspects of learning in lectures and labs, meta-cognitive processes encouraged by the use of self-assessment rubrics and followed up in lectures, and the fact that students had to struggle in labs to design experiments. We plan have a control study to find if these results are due to the maturation of the subjects or we observed some real transfer.

References

Barab, S.A., & Hay, K.E., (2001). Doing Science at the Elbows of Experts: Issues Related to the Science Apprenticeship Camp. Journal of Research in Science Teaching, 38 (1), 70–102.

Barnett, S.M., & Ceci, S.J. (2002). When and where do we apply what we learn?: A taxonomy for far transfer. Psychological-Bulletin, 128 (4), 612-637.

Black, P. & Wiliam, D. (1998). Assessment and classroom learning. Assessment in Education, 5 (1), 7-74.

Bransford, J.D., Brown, A.L., & Cocking, R.R. (1999). How People Learn: Brain, Mind, Experience, and School. Washington, DC: National Academy Press.

Bransford, J.D., & Schwartz, D. (1999) Rethinking transfer: A simple proposal with multiple implication. In A. Iran-Nejad & P.D. Pearson (Eds.), Review of Research in Education, 24, (pp. 61-100). Washington DC: AERA.

Catrambone, R., & Holyoak, K. L. (1989). Overcoming contextual limitations on problem solving transfer. Journal of Experimental Psychology: Learning, Memory, and Cognition, 15, 1145-1156.

Czujko, R. (1997). The physics bachelors as a passport to the workplace: Recent research results. In E.R. Redish and J. S, Rigden (Eds.), The Changing Role of Physics Departments in Modern Universities, Woodbury, NY.

Detterman, D. K. (1993). The case for the prosecution: Transfer as an epiphenomenon. In D. K. Detterman & R. J. Sternberg (Eds.), Transfer on Trial: Intelligence, Cognition, and Instruction (pp. 1-24). Norwood, NJ: Ablex.

Etkina, E., & Van Heuvelen, A. (2001). Investigative Science Learning Environment: Using the processes of science and cognitive strategies to learn physics. Proceedings of the 2001 Physics Education Research Conference (pp. 17-21). Rochester, NY.

Gentner, D., Loewenstein, J., & Thompson, L. (2003). Learning and Transfer: A General Role for Analogical Encoding. Journal of Educational Psychology, 95 (2), 393-409.

Gick, M.L., & Holyoak, K.J. (1983). Schema induction and analogical transfer. Cognitive Psychology, 15, 1-38.

Klahr, D. & Carver, S.M. (1988). Cognitive objectives in a LOGO debugging curriculum: Instruction, learning, and transfer. Cognitive Psychology, 20, 362-404.

Larkin, J. H. (1989) What Kind of Knowledge Transfers? In Resnick, L. B. (Ed.), Knowing, Learning, and Instruction: Essays in Honor of Robert Glaser. Hillsdale, NJ: Lawrence Earlbaum Associates, 283-306.

Mestre, J.P. (2002). Probing adults' conceptual understanding and transfer of learning via problem posing. Journal of Applied Developmental Psychology, 23, 9-50.

National Science Foundation. (1996). Shaping the Future: New Expectations for Undergraduate Education in Science, Mathematics, Engineering, and Technology. NSF, Directorate for Education and Human Resources Review of Undergraduate Education, May 15, 1996.

Salomon G., & Perkins, D. N. (1989). Rocky Road to transfer: Rethinking mechanisms of a neglected phenomenon. Educational Psychologist, 24 (2), 113-142.

Spiro, R.J., Feltovich, P.J., Jacobson, M.J., & Coulson, R.L. (1992). Cognitive flexibility, constructivism and hypertext: Random access instruction for advanced knowledge acquisition in ill-structured domains. In T. Duffy & D. Jonassen (Eds.), Constructivism and the Technology of Instruction. Hillsdale, NJ: Erlbaum.