Investigating Trajectories of Learning & Transfer of Problem Solving Expertise from Mathematics to Physics to Engineering

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Project Findings

The preliminary findings are organized by the research questions described in the Project Activites. For convenience of reading those research questions are repeated here.

Research Questions: During the first year of this grant we addressed the following research questions

1. What kinds of difficulties do students have when transferring their problem solving skills across problems in different representations?
2. How can we facilitate students' transfer of problem solving skills across problems in different representations?
3. How can we improve on online homework systems to obtain the data needed in the longitudinal study?
4. What views of mathematics held by electrical engineering students are important for oru study?

***Preliminary Finding for Research Questions 1 & 2*:**

We describe below the general trends observed in each of the interviews that we conducted as well as results of the phenomenographic data analysis

Impressions of Individual Interviews

Interview 1: The topic of interview 1 was 1D kinematics. All of the students were able to solve the original exam problem without difficulty. Students did have considerable difficulty in the graph problem when they were asked to find the time when the velocity was zero using the position vs. time graph. Most students confused velocity and displacement. They also confused average velocity and average acceleration. Finally, when prompted that they would need to find the slope of the graph, they inappropriately applied the formula for slope ('rise over run'). Instead they divided the y-value of the graph with the x-value of the graph to find the slope. Finally, students had the most difficulty in finding the value of acceleration at a given time from the position vs. time graph. This task was understandably challenging for the students as they had not completed a similar task in class previously.

Interview 2: The topic of interview 2 was work and energy in frictionless system. In the graph problem students were provided a graph of force vs. displacement for a spring and were expected to calculate the work done and potential energy of a spring. Students had considerable difficulty recognizing that the area under the graph was the work done by the spring. Instead they tried to calculate the spring constant ‘k’ from the graph. They were also unable to find the compression of the spring from the graph. Overall, students had considerable difficulty extracting information from the graph and using the graph as a tool to process information.

In the function problem, students were provided with an expression which expressed force as a function of displacement. Students attempted to calculate the spring constant ‘k’ using the function provided. They needed several hints to recognize that they need to integrate force to find work done by the spring. They were also unable to identify the limits of integration.

Interview 3: The topic for interview 3 was work and energy in a system with friction. Students had no significant difficulties in the original problem after they recognized the use of conservation of energy. In the graph problem they attempted to mimic the original problem by trying to use the graph to find the "coefficient of friction" of the liquid. In both the graph and function problems students confused the values of the variables to use in the problem.

Interview 4: The topic for interview 4 was rotational work and energy in a system with rolling friction. Overall, the performance in interview 4 was better than in interview 3. Students recognized use of integration as area underneath the graph. When asked, they said they remembered that from the last interviews. In the graph problem, students needed several hints to recognize approximation for area under a non-linear curve. In both the graph as well as the function problems students faced difficulties with units in that they did not realize that they needed to multiply the differential angle of an arc (in radian) with the radius of the arc to determine the differential distance. After the first few interviews, we changed the hints for the function problem. Instead of hinting about *ds*, which didn't seem to make much sense to them, we let them evaluate the integral (in N.rad) and then convert it into N.m.

Overall Impressions

Our overall impressions from all four interviews can be described in terms of the following themes

- *Case Reuse*: Students mimic previous problem whenever possible. This is expected behavior and can also be productive when used appropriately. However, in most cases using the original problem worked against students while they were trying to solve the graph and function problems.
- *Interpreting a Graph*: When needed to calculate something from the graph, the first thing that came to students’ mind was the slope. The recognition that the area under the graph was relevant to the problem was realized only after the appropriate hints to the students.
- *Physical Meaning of Differentiation and Integration*: Students do not appear to know the physical meaning of derivative and integration, although they could compute those things easily. So hints about the meanings were not useful when students were expected to use the graphical or functional interpretations of these terms.

- *Using Appropriate Physical Principle*: Students do not appear to know that Newton's Law and Energy methods are two different methods. So they sometimes combined both methods, which made the problem tricky and led to confusion.

Phenomenographic Analysis

The pseudo-transcripts were coded for students' *difficulties* during problem solving as well as for *hints* provided by the interviewer to help the students solve the problems. The codes were then collapsed into categories for each the *difficulties* and *hints*. Below we describe the categories for each.

Categories for Difficulties: A total of 16 codes were collapsed into 6 categories for the difficulties that students faced while solving the problems.

- Appropriate physical principle (PRINCIPLE): Students were not sure whether energy was conserved in the problem and unclear as to whether or not to use the principle of conservation of energy.

- Appropriate use of physical quantities (QUANTITY): Students were using certain physical quantities inappropriately. For example, they were attempting to find the potential energy of a spring even when the spring in the system was not being used in problem.

- Meaning and use of formula (FORMULA): Students apparently did not understand the meaning of a formula and were unable to use it appropriately. For instance, they included only work done by friction in 'Work-Kinetic Energy' theorem, and not the work done by other forces.

- Processing information from graph (GRAPH): Students were unable to process information from a graph provided. There were two levels of difficulties: First, students were unable to read off values from the graph e.g. finding the value of the x-intercept. Second, students were unable to correctly interpret the physical meaning of the graph, such as the area under the graph is the work done.

- Using mathematical techniques (MATH): Students were unable to use the correct mathematical formula or were confused between two formulae e.g. confusion between sine and cosine.

- Minor calculation errors (CALC): Students made simple mathematical errors in calculation such as not squaring velocity in calculating kinetic energy.

Categories for Hints: A total of 20 codes were collapsed into 7 categories for the hints that were provided to the students to help them overcome the difficulties. Almost 80% of the hints were provided in the form of questions rather than direct statements to students.

- Appropriate physical principle (PRINCPLE): Students were asked a question that got them to think about whether or not a particular principle was applicable. For instance, do you think energy is conserved here or not?

- Re-gathering info from problem statement (INFO): Students were asked to take another look at the problem statement so that they could attend to the necessary information that would help them decide whether or not a particular principle was applicable, e.g. was there any friction in the problem?

- Appropriate use of physical quantities (QUANTITY): To enable students to decide which physical quantity was applicable in a problem, students were asked a leading question such as what energy does a ball have at initial point?

- Meaning and use of formula (FORMULA): Students were asked what appropriate value of a physical quantity should be used while calculating another physical quantity, such as what is the appropriate value of 'h' when calculating P.E.?'

- Processing information from graphs (GRAPH): Students were asked one of two kinds of questions. First, they were asked to directly read of information from the graph, such as at 'x=0.2m' on the graph what is the force? Second, they were asked a more indirect question that would prompt them about using the graph to accomplish a particular task, such as, how do you calculate work using a graph?

- Using mathematical techniques (MATH): Students were directly reminded of a formula that they may have forgotten, such as 'sine' is opposite/hypotenuse.

- Minor calculation errors (CALC): To enable students to recognize calculation errors they were often asked whether their result made sense.

Summary of Preliminary Results for Research Questions 1 & 2

Below we address each of the research questions that we posed for this study;

- What kinds of difficulties do students have when transferring their problem solving skills across problems in different representations?

We found that students had greater difficulty transferring their problem solving skills to graphical problems than to function problems. We also found that students had considerable difficulties with physical interpretations of the formulae and mathematical operations, such as derivatives and integrals, although they had no difficulty in performing these operations.

- How can we facilitate students' transfer of problem solving skills across problems in different representations?

We found that students needed hints to interpret graphs and extract information from them. There were two levels of hints that were needed. The first one was simply to read off information from the graph. The second was to use the graph as a tool to perform an operation and gather relevant physical information, such as determining the work done from the area under the graph.

Finally, we found that students, with appropriate hints, can use the physical meaning of a mathematical operation (e.g. integration) to help mediate their interpretation of a graph, so sequencing of representations can facilitate/hinder transfer.

Preliminary Finding for Research Question 3

Student reactions to these tools have been generally positive, where the ease of answer entry plays a large role in the experience. Quantitative correlations between module scores, grades on written examinations, and performance in previous mathematics courses have demonstrated variable clarity, but qualitative assessments of the technology-facilitated environment point to a clear increase in student learning and engagement. Instructor benefits are apparent with regard to grading time saved, grading consistency, confidence in student accountability for work submitted, and information regarding when/where students work that is difficult to obtain any other way. Graduate student investment is significant in terms of maintaining the module database and responding to student queries.

At this time we have no preliminary results for Research Questions 4.