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Investigative Science Learning Environment

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Investigative Science Learning Environment (*ISLE*) is an introductory physics learning system that makes a conscious attempt to mirror the processes that physicists use in their real-world practice while constructing knowledge and applying it for useful purposes (Etkina and Van Heuvelen, 2001). One of the major goals of *ISLE* is to help students master the inductive and deductive elements of scientific discovery.

ISLE students start each conceptual unit by observing carefully selected physical phenomena. They collect data with an open mind. Students construct ideas/rules to explain their experimental observations. They are encouraged to suggest multiple explanations for the same experiment. The fact that all explanations have equal weights before they are tested allows students to express their ideas, often based on every-day experience, freely without waiting for authority for validation. Students can use their contextual and epistemological resources to help in constructing explanations (Hammer and Elby, 2003). Students then evaluate their explanations/rules using hypothetic-deductive reasoning to predict the outcomes of new testing experiments. After performing the testing experiments, they revise their explanations when necessary. Sometimes testing experiments reveal new features of the phenomenon that students try to explain, and the cycle starts again. They then use tested explanations/rules to explain every-day experiences and to solve problems. Students follow similar cycles for each conceptual unit and continuously reflect on "how they know what they know." (An example of *ISLE* cycle is given in the appendix). At each stage students work collaboratively (in groups), sharing ideas and trying to convince each other. This approach resembles the processes that the scientific community uses to acquire knowledge.

This aspect of *ISLE* instruction differs from traditional and from some reformed approaches to physics instruction in several ways. The instructor does not provide students with ready-made physics concepts to discuss nor shows experiments to illustrate concepts/rules that were presented earlier. *ISLE* students do not read the textbook before coming to class. The instructor *does not elicit predictions* before the observational experiments. Students' alternative ideas are addressed naturally at the concept construction or concept testing stages of the cycle.

Another feature of *ISLE* is that students master the concepts that they devised using various thinking and learning strategies. Students are active participants in all parts of their learning. They learn to represent physical phenomena in multiple ways (Van Heuvelen & Zou, 2001). These include sketches, concrete physical representations (motion diagrams, energy bar charts, free-body diagrams, ray diagrams, and so forth), graphs, and algebraic expressions. They learn to convert one type of representation for a process to other types. The concrete representations are used to help construct accurate mathematical descriptions of processes.

After concepts have been constructed and tested, students use the different representations to reason qualitatively and quantitatively about physical processes – a strategy commonly used by scientists. Students learn to take a more complex situation apart, solve the parts, and reassemble the parts to answer a bigger question. They learn to design experiments, for example experiments to solve practical problems.

Students are assessed for conceptual understanding, for problem-solving ability, and, most importantly, for their use of various scientific abilities. We have and are developing activities that help students acquire some of the abilities used by scientists in their work: experiment design, model building, use of multiple-representations, and evaluation. Similar tasks are used for formative assessment activities to determine the degree to which the students have acquired these abilities and to simultaneously provide feedback to the students (Black and Wiliam, 1998).

The *ISLE* system has been used in large (over 500 students) classes and in smaller classes. The format for the instruction depends on the number of lecture, recitation and lab classes each week. For example in one large class, a two-week unit starts with students observing phenomena in the first lecture. They work in groups of two/three to record their observations, look for patterns in these observations, analyze the experiments in various ways to help produce qualitative explanations that account for their observations. They use the different explanations to make predictions about a testing experiment proposed by the professor or suggest their own testing experiments. This is done through interactions with representatives of the groups, voting, or an electronic response system. The testing experiments are used to discriminate among the different explanations. In this lecture or in a second one, students identify relevant physical quantities. Students look for patterns in experimental data that relate these quantities—to devise a relationship between them – a physical rule or a law. These rules are then subjected to experimental testing again. Then students use the qualitative explanations and the rules to reason about new processes, to represent them in multiple ways, and to solve problems of easy to moderate difficulty. All this happens in an interactive format using a peer instruction approach.

During one or more recitations in this first week or early in the second week, students work in groups on problems—qualitative problems, multiple representation activities, and often on more complex multi-part problems. They also evaluate solutions to the problems devised by other students. The lab related to this conceptual area occurs during the second week and involves more complex quantitative testing experiments and experiment problems. Students are sometimes responsible for designing an experiment to test a concept or an experiment to solve a problem. They practice hypothetico-deductive reasoning (if, then, but, therefore as in Lawson, 2003) to make predictions and to assess the results of the experiment. In lectures during this second week, a new cycle starts. As stated earlier, different formats are used depending on the size of the class and the class time available for each part of the course—lecture, recitation, and laboratory.

ISLE cycle for projectile motion (done after kinematics and dynamics)

At the beginning of the unit on projectile motion students in lecture observe a moving cart shooting a metal ball upward. They repeat the experiment several times for different speeds of the cart and record the patterns in their observations (the ball always returns to the cart). Then they work in groups to construct explanations based on the patterns in their observations. The instructor encourages them to think of different possibilities (the ball is somehow attracted to the cart, may be it is a metal ball and there is a magnet in the cart; the ball continues moving horizontally the same way as the cart – horizontal motion is independent from the vertical, etc). After the groups share their explanations, they then design testing experiments to determine if the explanations work. For example to test the magnet explanation, students suggested shooting the ball and then stopping the cart – if the cart attracts the ball, it will come back to the cart. To test the independence of the horizontal motion of the vertical motion they suggested holding the ball and then dropping it while walking at a steady pace – if the vertical motion is independent of the horizontal, the ball should land by the feet. The next step is to identify physical quantities and find relationships between them empirically or by derivations using prior knowledge (students combine familiar ideas of motion with constant speed and with constant acceleration). Then students design experiments to test the relationships – for example predict where a projectile will land in a laboratory. Finally students apply these concepts and relationships to explain their relevant life experiences (for example, real-life experiences related to sports) and to solve traditional and more complex problems in recitations.

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