Shifting Student Outcomes with the Investigative Science Learning Environment

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Scientia

SHIFTING STUDENT OUTCOMES WITH THE INVESTIGATIVE SCIENCE LEARNING ENVIRONMENT

Devising novel ways to engage students in science courses is a long-standing goal of many educators, but even the best applications of traditional teaching methods often fall short. A team of scientists, led by **Professor Eugenia Etkina**, has developed a novel method for teaching physics – the Investigative Science Learning Environment – that is transforming how students learn physics. Their next step is to make this method available to the masses.

The Need for Improved Science Education

In a world that is increasingly technology driven and facing global problems that require scientific reasoning to address, science education is more important than ever. However, traditional memorisation methods of teaching science have failed many students, leading to a general population that holds many erroneous ideas about how science works and a limited understanding of how scientists come to conclusions.

Over 20 years ago, Professor Eugenia Etkina from Rutgers University developed a novel method of teaching physics that holds promise for a more scientifically literate future. Her Investigative Science Learning Environment (ISLE) teaching system engages students in learning how to think like scientists through experimental design and analysis.

Professor David Brookes from California State University has been using the method and contributing new activities for the past 15 years. Professor Matthew Vonk of the University of Wisconsin and Peter Bohacek of the Pivot Interactives have developed ways of simulating student experimental design through arrays of videos for the students who do not have access to real equipment. They formed a partnership with the ISLE development team to explore ways for students to engage in scientific investigations in non-traditional settings such as an online learning environment.

A Winding Path to a Better Way

Professor Etkina began her career as an educator in the Soviet Union, teaching physics in a high school in Moscow. As a motivated young teacher, she spent countless hours preparing for each of her classes, designing lessons that revolved around intricate physics demonstrations. Her lessons were well received, and she was regarded as one of the best physics teachers at her school. However, she would soon experience two major revelations that shifted her teaching philosophy radically.

First, Professor Etkina came to the realisation that most of her students would not go on to become physicists, but they would all become members of society. While they might not have a strong need to understand particle interactions or calculate object trajectories, they would all encounter information that they'd need to evaluate with a critical eye. She envisioned a future in which her pupils, regardless of career, would approach the world like scientists. She wanted them to ask questions such as, 'How do you know this?', 'What assumptions were made?', and 'Is there evidence for that conclusion or is it a best guess?' She wanted her students to learn the principles physics, of course, but more importantly, she wanted them to understand how these principles were discovered in the first place, in other words, how to think like a physicist.

Second, a chance encounter with a former student led her to a shocking insight. The young man had been a diligent 'A' student that enjoyed her class. However, when she ran into him years later, he admitted that the only thing he really remembered was a presentation he had given on a topic he had researched himself. Despite her meticulous physics presentations, the student only remembered material he had learned on his own. She realised that instruction that facilitated students in making their own discoveries would be more effective than any demonstration she could give.

Professor Etkina began experimenting with novel ways to engage her students in active learning, with the goals of teaching them to think like scientists and encouraging them to learn some processes on their own. She had students work in small groups to explain physics phenomena that she demonstrated during class. With Professor Etkina's guidance, they had to design and run their own experiments, collect and analyse their own data, and discuss their findings with their classmates. From these exercises, she formed the foundation of a novel physics learning system, which she would later bring to the United States and develop into the ISLE teaching system.

Learning Through Exploration

The ISLE system starts with the students performing a simple physics experiment suggested by the instructor, observing the outcomes and finding patterns. Students are asked to describe what they see without making any predictions about the outcome. They are asked to approach the phenomenon free of expectation. The students then break into groups and are encouraged to come up with as many potential explanations for the patterns they found as they can. Next, students take their list of possible explanations and, with instructor guidance, design experiments to test each one.

Before any testing experiments are performed, the students must make predictions based on their explanations, requiring them to carefully consider the assumptions they are making about the process. The students then perform the experiments they have designed and analyse the outcomes. When their predictions match the outcomes, they are encouraged to consider whether alternative explanations would produce the same result. When their predictions do not match the outcomes of the experiments, they go through a review of their additional assumptions or propose new explanations and experiments. Explanations that survived many tests are later used to solve practical problems. Critical thinking is encouraged at every step of the journey.

The ordering of activities is perhaps one of the most unique twists of the ISLE curriculum. In the conventional physics classroom, students are expected to have read the text for a topic prior to starting it in class, with the idea that they will be prepared to discuss the topic when they arrive. In the ISLE classroom, students are discouraged from reading the associated chapters of their textbook until after their experiments and discussions for a topic are complete. This encourages a genuine sense of scientific exploration as the students navigate their experiments. Instead of reading explanations in a book and picking the ‘right’ experiment to do, they are relying on their own ideas and curiosity to move their knowledge forward. When they read the textbook afterward, they are able to tie the text to their own concrete experiences.

Transforming Student Understanding

The ISLE system has proven effective at providing students with memorable learning experiences that help them think more like scientists. When Professor Etkina and her colleagues evaluated the system at Rutgers in a physics class for non-physics majors, their results were beyond impressive. After only eight weeks of labs in an ISLE-based course, the vast majority of students were able to independently perform feats such as designing their own experiments, collecting and analysing their data, evaluating their results, and challenging their scientific assumptions.

When solving complex physics problems, over half were drawing diagrams to conceptualise their solution, at nearly quadruple the rates seen in traditional classrooms. Almost half of these non-physics majors were able to explain how they would go about testing multiple potential explanations for a phenomenon – a genuinely startling feat when you consider that none of their non-ISLE educated peers who were actually majoring in physics could do the same. In fact, only a handful of first year physics graduate students had reached this level of mastery – the ISLE students were discussing problems in a manner comparable to many advanced graduate students.

Perhaps the most exciting result was that they could adapt the reasoning processes they had mastered in physics to approach experimental problems in biology. They were able to recognise the important parts of the problem, create visual representations to explain their reasoning, figure out how to collect data with the equipment on hand, and analyse and evaluate their results. The ISLE students had truly learned to approach the world as scientists.

Bringing ISLE to Students Everywhere

The ISLE system has been a smashing success in classrooms and has now been adapted into a college textbook. While it is a great benefit to students that are lucky enough to join these classes, Professor Etkina, Professor Brookes, Professor Vonk and Bohacek now plan to make the ISLE learning process available to students all over the world.

With funding from the National Science Foundation, they are working to develop materials for a virtual ISLE resource – a collection of interactive videos and other tools that work to replicate the full ISLE process online. The materials include interactive videos, measurement tools, embedded graphing tools and supporting questions appropriate for students in middle school through college, along with guidance for physics teachers who wish to use the video-based ISLE in their classroom.

Describing the goals of her team’s newest venture, Professor Etkina says, ‘How can we recreate the freedom and creativity of students designing their own experiments with real equipment in situations when only videos are available? How many variations of the same experiment do we need to video so that the students feel that they are making their own choices in what to investigate? How do students reason when they interact with the videos of experiment not the real experiments? Our project aims to answer these questions.’

These are not small challenges. Though it is easy to offer observational experiments for the ISLE system though video, it is difficult to recreate the experience of students having unlimited choices to test the explanations they come up with. Unlike a physical classroom equipped with an array of experimental equipment that offers broad options for students to come up with their own experiments for a problem, the options available in a virtual classroom are limited by what its creators choose to include.

The team’s solution is to create online activities featuring matrices of videos of testing experiments. Unique digital tools invented by Bohacek and Vonk, embedded in the videos, allow students the freedom to explore and design investigations. Students must use their creativity to choose what and how to measure, similar to how they would design experiments in a fully equipped lab room. Foreseeing all possible ideas that students can come up with is not easy, but this is where the collective teaching experience of the team, knowledge of physics education research, and experience of implementing ISLE help. Feedback so far is promising, with teachers in schools with limited funds and equipment noting that the videos let them expand the experiments available to their students and the students expressing that the videos help bring concepts together.

Initial studies of student outcomes suggest that the virtual ISLE holds as much promise as hands on experiments, particularly for topics where real-life experimentation can become finicky and tedious for students. The team is currently working to understand the gaps in the virtual labs and find solutions to fill them. ‘So far we see that certain physics topics are easier to investigate with real equipment and certain topics are better with videos. But we do not know the optimal level of help that we need to provide to the students who are working remotely with the videos,’ Professor Etkina explains.

The Future of Science Education

The ISLE team’s work is demonstrating the potential for active science learning to transform how students interact with and understand the world. By expanding this system into a virtual learning environment, they are making cutting-edge science education accessible to students around the world.

Meet the researchers

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Professor Eugenia Etkina began her career as a high school physics teacher in Soviet Russia. She later continued her education to earn a PhD in Physics Education from Moscow State Pedagogical University. In 1997, she joined the faculty of the Graduate School of Education at Rutgers University, where she is currently recognised as a Distinguished Professor. Her award-winning work focuses on novel methods of teaching physics to students of all levels and physics teacher preparation.

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After obtaining a Master's degree in Theoretical Physics from the University of Cape Town and a second Master's in Physics from Brandeis University, Dr David Brookes earned his doctorate in Physics Education from Rutgers University. In 2015, he joined the Physics Department at California State University, where he continues his research in physics education.

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Prior to diving into physics education, Peter Bohacek spent over a decade in a successful career in digital electronics. He began teaching high school physics in 2002, and in 2011 he completed his Masters of Science Education with an emphasis in Physics. Bohacek is the co-founder of the Direct Measurement Video Project, a video library of physics experiments for educational purposes.

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Dr Matthew Vonk earned his PhD in Physics from the University of Minnesota before joining the faculty at the University of Wisconsin River Falls in 2004. He currently chairs the AP (Advanced Placement) Physics-C Exam Development Committee and recently served as a Fulbright Traditional Scholar in Medellín, Colombia. His current research focuses on electronics design and physics education via video-based experiments.

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