The Investigative Science Learning Environment (ISLE) approach to learning physics

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Abstract. In a plenary talk “Investigative Science Learning Environment (ISLE): helping students learn physics by practicing it and be empowered in the process” at the SEA-STEM 2020 conference 1 (Eugenia Etkina) described the ISLE approach to learning and teaching physics, shared examples of activities and presented evidence of student learning. In this paper I, with my collaborators David T. Brookes and Gorazd Planinsic will briefly summarize my presentation and provide a list of resources for those who wish to learn more about the ISLE approach and to implement it in their physics courses.

1. Introduction
The ISLE approach is an approach to learning and teaching physics which has two major goals:
(1) to help students learning physics by engaging them in practices that mirror the processes and procedures that practicing physicists use when developing and applying physics knowledge (this means that everything that happens in the classroom and at home related to students learning of physics mirrors the activities in which practicing scientists engage) and
(2) to enhance student well-being, motivation, sense of belonging, and perseverance. This means that the decisions that the instructor makes while planning, enacting and assessing the instruction support student intellectual and emotional growth.

These two goals make the ISLE approach an example of an intentional approach to curriculum design [1]. MacMillan and Garrison [2] argue that teaching is an intentional activity involving beliefs and values, and wherein teachers engage. The ISLE approach is very clear about the intentionalities. The above two goals correspond to the two intentionalities: how students learn physics and how they feel about themselves while learning it.

The key to understanding the first intentionality of the ISLE approach is that we believe that the product of knowledge cannot and should not be separated from the means by which it came to be known. Therefore, first intentionality of ISLE is that students should learn physics by engaging in activities that mimic the authentic knowledge-generating activities of practicing physicists.

However, the first intentionality of ISLE by itself is not enough to facilitate student learning on its own. If we want students to construct knowledge by thinking like physicists, they need to be motivated
to engage in the process. They need to feel that they can create knowledge and that this knowledge is meaningful and useful in their lives. The second intentionality of ISLE is that our curricular design decisions should enhance or nurture human well-being rather than harm it. To summarize, learning physics should empower you, make you feel like you can do anything, not make you feel stupid, inadequate, or that you do not belong. Both intentionalities are difficult to understand without specific examples.

2. Intentionalities of the ISLE approach

2.1. First intentionality of the ISLE approach: engaging students in “doing” physics while learning it

In the traditional approach to teaching and learning the instructors are focused on what they will do to explain the material better, what experiments they will show, what problems they will assign and how they will grade student work. The students usually sit in a classroom with seats in rows facing the teacher and listen to the explanations taking notes. The students do not question the information that is supplied to them. The instructor grades them on how they understand this information and how they apply it to solve problems. The grades for student work are given and those are recorded. The students do not have an opportunity to improve their work (in cases that they are allowed to do it, the second attempt receives a reduced grade for being second).

If we examine most of the contemporary interactive engagement methods, we find similar issues. There are many models of interactive engagement methods. One popular approach is the “flipped classroom” [3] where the students read the textbook (or watch a video with the instructor explaining the material), then come to class and discuss what they read through answering questions posed by the instructor. They often work in pairs and participate in voting for the best answer. An example of a flipped classroom in physics education is the method of Peer Instruction [4]. While the students in these classrooms work collaboratively answering questions and lecturing is limited, the knowledge that students begin with comes from authority. Students get acquainted with physics concepts by reading the book or watching a video with an authority figure on the screen. Such methods lead to more learning than traditional lecturing, but what message about physics are they sending to the students? One answer is that science is an area of study that can be learned by reading the book and discussing what you read in class. The approaches to assessment in such courses are similar to traditional approaches. Students solve problems applying the knowledge and receive grades.

If you think about the practice of physics or any other science, you will see clearly how the practices of traditional teaching and even the practice of most interactive approaches contradict its every step. The heart of science is its experimental nature, collaboration of its participants, peer review, and continuous improvement of one’s work. We revise and resubmit papers until they are deemed worthy of publication, we revise and resubmit grant applications. We collaborate with our peers and present our findings to large audiences that critique it. Can these practices find their way to student learning? One might argue that scientists have a lot of background knowledge, they read research papers and are trained for a long time. How can students, who are just starting to learn, engage in similar activities? It turns out that this is entirely possible.

Imagine that you walk into a classroom where students are sitting in groups of 3-4 around round tables. On each table there is a small white board and 3-4 markers of different colors. Each table has a piece of white paper. The teacher walks around and puts a streak of rubbing alcohol on each paper and asks the students to observe it (http://www.islephysics.net/pt3/experiment.php?topicid=7&exptid=40). After the students watch what is happening for 3-4 minutes (the wet spot dries) they are invited to discuss in groups their observations without using fancy scientific terms. They write their observations on the white boards each using their own color marker. Then they lift the boards and everyone sees what the rest wrote. The discussion of the patterns emerging from their observations starts. The students say that alcohol disappeared, that the wet spot shrank, that the process happened slowly, gradually. Once the whole class agrees on these patterns, the instructor asks them to focus on the gradual aspect of the disappearance first. What could be the inside structure of the alcohol to allow it
to disappear gradually, i.e., not all at once? Usually, the students say that it could only happen if the alcohol was made of smaller parts, or pieces.

Now the next step of group work comes: the students discuss in groups and put on the white boards all possible mechanisms (hypotheses) that could explain disappearance of small pieces and then share these with the class using the same approach. To reduce the focus on the “right” answer we call these mechanism “crazy ideas” – anyone can come up with a crazy idea and therefore everyone feels that they can participate. Groups of students usually come up with several “crazy ideas”: the paper absorbed the pieces (1), the air absorbed the pieces (2), or the pieces “jumped” out of the paper (3). Now the students have three (sometimes more) hypothetical mechanisms. How do we know which one is correct? Most students say: Test them! But how to test? What does it mean to test in science? Here the teacher explains that testing in science involves designing a new experiment whose outcome can be predicted using the hypothesis under test. If the predictions based on different hypotheses for the same experiment are different, it is a good experiment, if they are the same, the experiment will not help distinguish between different hypotheses.

The groups get together again to brainstorm possible experiments. They come up with the following experiment quickly: put the wet paper on a scale. If (1) is correct, the reading of the scale will not change as the paper dries. If (2) and (3) are correct, the reading will go down and eventually be the same as for the dry paper.

The experiment is easy to perform and the outcome matches the predictions based on (2) and (3). (1) is rejected and (2) and (3) are not.

How to test the hypothesis (2) that involves air? Usually, the students suggest wrapping wet paper in a plastic wrap to prevent interaction with air. If (2) is correct, the paper should not dry but it should not dry also if (3) is correct. Thus, the experiment will not allow to differentiate between these two hypotheses. At this moment the instructor leads a discussion of what makes a good testing experiment. The search for new ones goes on.

In our experience, the most attractive hypothesis for the students is that air absorbs the pieces of alcohol (2). How can they test it? Eventually a group of students comes up with putting wet paper under a vacuum jar and have another one, similarly wet outside. If air takes alcohol parts, then the paper under a vacuum jar should dry slower than outside. If the pieces jump out (3), then removing air should not affect the rate of drying. This experiment is easy to perform if you have a jar or use the video at (http://www.islephysics.net/pt3/experiment.php?topicid=7&exptid=45). To students’ surprise the paper inside the jar dries faster! The “air” hypothesis is disproved. What is next? Testing the hypothesis of moving pieces. We leave the readers to observe the experiment and come to the conclusions themselves (http://www.islephysics.net/pt3/experiment.php?topicid=7&exptid=47). The moving parts hypothesis is not rejected.

Looking back, we see that the students observed a simple experiment (drying alcohol), worked in groups to come up with two patterns: disappearing (1) of alcohol occurs gradually (2) devised one explanation for pattern 2 and several for pattern 1, tested them in multiple experiments and rejected all explanations for (1) except the motion of little pieces of alcohol. To summarize, the students on their own constructed the concept of the particle nature of matter and the idea that these particles are moving. These two ideas are the foundations of the kinetic molecular theory – the most fundamental theory of nature. Once the students develop the concept of the particle nature of matter and the motion of particles, they can proceed to applications of these ideas. They can explain why we put tea bags in hot water, not in cold water, why baked goods smell when they are hot much more, why our lips dry out in the mountains and so forth. The process through which the students discovered and applied these fundamental ideas follows the ISLE (Investigative Science Learning Environment) approach and it is shown in Figure 1.

Note, that in the process described above the students participated in most important science practices: they observed natural phenomena, devised multiple explanations for them and systematically tested them with the purpose of ruling out not proving. They worked collaboratively,
shared their ideas, and continuously improved them. They were not looking for correct answers but were engaged in an authentic scientific process. They continuously improved their models without being punished for devising the “wrong” ones.

This is just one example of how one can bring real science practice into the classroom. We have developed similar sequences for all concepts of introductory physics (see the Section Resources at the end of this paper).

![Figure 1. Elements and connections of the ISLE process](image)

2.2. Second intentionality of the ISLE approach: using physics to help students grow and empower them in the process

Traditionally physics is viewed as a very difficult subject that is accessible for very few people who are smart and good in math. It is taught as a series of equations that the students need to memorize and apply to solve problems that deal with simplified systems (blocks on frictionless inclined planes) and have one correct answer. The students are assessed on their ability to answer a barrage of questions (in US these questions are usually multiple choice) in a short time. Those who are slow or need more time to learn, have reading comprehension issues or are behind because of their math skills, become lost in this game quickly, drop out and begin thinking of themselves as incapable of learning physics. What can we do to change the situation?

Here, we use the knowledge developed in cognitive science, disability studies, and science education help us answer this question. When the students observe simple experiments, discuss patterns, devise explanations and continually test them in new experiments, they work in groups using small white boards. They share their ideas freely and are encouraged to use simple language, scientific terms are not allowed. They need to come to a consensus inside their groups before they share their ideas with the rest of the class. After group discussions are finished and the groups are ready to share, the instructor either invites representatives from each group (called spokes people) to present their group’s findings and solutions or asks representatives of the groups to walk around, study their peers’ whiteboards and note the differences. Then each group has an opportunity to revise their reasoning/solutions and reflect on the changes.

This part of student learning creates a level-playing field where nobody has an advantage of prior knowledge and experiences. Such work creates a non-threatening environment. The role of the instructor here is to select the first observational experiment(s), scaffold students’ discussions, and introduce the tools for reasoning. These tools are representations other than mathematics (in physics
these are motion diagrams, force diagrams, momentum and energy bar charts and many others – see examples in the Resources section 1 [5]. When the students finally develop the concept and test it, they proceed to applications – solving experimental or paper-and-pencil problems.

When the students go home, they work on the assigned homework. If the homework is graded, the students have an opportunity to revise and improve their work without punishment (meaning that if the work is good, they get 100%). Back in class, the instructor might give them an individual or a group quiz to assess their understanding. Here, again, if a student does not do well, they have an opportunity to improve their work and are judged based on the final result. If they achieve a 100% their grade will be a 100% not a percent less because of the second or third attempt. The specific arrangements differ from a course to a course, but the main outcome is the same – the learning is encouraged and rewarded.

When a complicated experiment is in order, the students engage in formal “labs”. They work together designing an experiment, assembling the apparatus, collecting and analyzing data, arriving to conclusions and creating a group lab report [6]. There are no cook-book instructions on how to proceed, but guiding questions and self-assessment rubrics that scaffold student work [7]. The instructor uses the same rubrics to assess the reports and again, if the improvements are needed and are done by the students – they receive full credit. Now days most of this work is done through file sharing software (google docs is one example) which allows the teacher to see student work in real time, see who is doing the work in a group and how long it takes.

You might be wondering how the described activities help students grow as learners and empower them in the process. How do these activities support students intellectual and emotional growth? As always, the devil is in the details. Below is the list of the details.

1. When students observe the initial “observational” experiments they have to describe their observations using simple language – this step levels the playing field for those who might have taken a physics course before and those who have not. As the students are not asked to predict the outcomes of these experiments before observing them, their intuition is not put to the test and no one feels unsuccessful.

2. When students look for patterns, they use tools other than algebra to analyze data (graphs, motion diagrams, force diagrams, energy bar charts, etc.) – this step helps those who are not strong in algebra.

3. When students explain their observations, they do not need to come up with the “right answer” but instead devise explanations that are experimentally testable. This allows them to base new ideas on what they already know.

4. When students design experiments to test their explanations, they learn that rejecting an explanation is not a “bad thing” but instead, a productive step that is a part of authentic scientific discovery. Testing explanations and devising new ones allows the students to improve their reasoning without punishment.

5. When engaged in steps 1-4 students collaborate, which makes students with different strengths shine at different points, empowering individual students and the whole class as a community.

6. When being given an opportunity to revise their assignments without punishment, the students begin to value learning and perseverance instead of a pure grade. This allows different students to experience success at different points in time. The fact that assignments call for using different representation not just mathematics helps those with different skills, including those whose Mother tongue is not English.

To summarize, the ISLE approach to teaching physics is more than a logical progression of activities in which students engage. It allows the students to be successful at every point of their learning, build on their prior knowledge, develop perseverance and confidence. As Julie Maybee, a professor of disability studies commented in her recent book [8]: “ISLE thus provides an example of an approach to teaching that avoids classifying people and worries instead about classifying and developing ways in which people with a variety of skills and abilities can access the content. In this case ISLE focuses on creating a learning environment that produces a variety of ways for students
with different skills and abilities to engage in socially meaningful, cooperative and student-initiated activities to build on what they know and access new knowledge about physics (p.190).”

3. **Three key elements of the ISLE approach**

A detailed description of the ISLE approach and how to implement it in your classroom can be found in the book by Etkina, Brookes and Planinsic, “Investigative Science Learning Environment: When learning physics mirrors doing physics” [5] and the details of teaching every topic of introductory physics through the ISLE approach can be found in the algebra-based physics textbook “College Physics: Explore and Apply” [9]. Here we focus on three fundamental elements of the approach that work together to address the intentionalities of ISLE.

3.1. **Key element 1: Learning process and learning tools**

Consider the example of “drying alcohol” described above. When constructing any concept students work in groups. They observe carefully selected simple experiments, identify patterns in them and propose “crazy ideas” – mechanistic explanations for the patterns or causal relationships between the variables. They then proceed to test their crazy ideas by designing new experiments and using their own crazy ideas to make predictions of their outcomes. When the outcomes match the predictions, the students design more testing experiments and eventually proceed to applying the new ideas and when there is a mismatch, they revise the ideas.

The ISLE approach changes our understanding of the role of experiments in learning physics. Instead of dividing experiments that students perform or observe into “demos” and ‘labs” or “hands-on” the experiments start playing the roles that they play in physics – the experiments that lead to the development of new hypotheses (we call them observational experiments), the experiments that lead to the test of the new hypothesis (we call them testing experiments), and experiments that allow for application of multiple tested and accepted hypotheses. Looking back at the example we showed at the beginning of this paper, you see that observing a wet paper strip was an observational experiment, weighing the paper on a scale and putting it under a vacuum jar, were testing experiments and putting tea bags in hot water was an application experiment. Below we show another example of three types of experiments from the area of DC circuits. Notice, that it is the students who design the experiments, they do not perform the experiments following step-by-step instructions. This is another feature of the ISLE approach [5].

**Observational experiment:** Design an experiment to find a relation between a potential difference across and current through a commercial resistor.

**Testing experiment:** Design an experiment to test whether this relation applies to an incandescent light bulb.

**Application experiment** (after students learn that the potential difference across glowing LED is approximately constant): Design an experiment to use this relation to construct a circuit which can power an LED without overloading it.

To help the students reason through this non-linear, but a repetitive ISLE process (see Figure 1) we provide them with reasoning tools. Traditionally, in physics education the most widely used tools are algebra and calculus. In the ISLE approach we use a whole library of graphic tools – motion and force diagrams, momentum and energy bar charts and so forth. They serve as bridges between phenomena and algebra, helping all students learn. The following example will help clarify the role of multiple representations in helping students reason like physicists (see Resources, ALG, Activity 7.9.2): “Imagine that a ‘space elevator’ has been built to transport supplies from the surface of Earth to a spaceship that is located very far away from Earth (so far that the gravitational interaction of the ship and Earth can be neglected). The elevator moves at constant velocity, except for the very brief acceleration and deceleration at the beginning and end of the trip.
Draw work energy bar chart representing the process for the system supplies-Earth. What is the gravitational potential energy of the system at the infinite distance from Earth? What sign should the gravitational potential energy of interaction have when the supplies are on Earth?

Reasoning that at the infinite distance form Earth the energy of interaction between supplies and Earth should be zero and the elevator does positive work on the system (the force and the displacement vectors point in the same direction) the students draw a bar chart and realize that the initial gravitational potential energy of the system should be negative. As this finding is applicable for any bound system, the students armed with this knowledge can now tackle ionization of atoms, evaporation of liquids, photoelectric effect and many other phenomena that are very difficult to explain without energy analysis.

3.2. Key element 2: Assessment and community of learners
If we want our students to learn to think like physicists, we need to assess how they think, not whether they can find the right answer. To assess students ability to reason like a physicist and to simultaneously help them develop these abilities, we have developed a set of self-assessment rubrics that help students and teachers focus on the most important aspects of physics reasoning. These rubrics and corresponding research can be found in [7] and at https://sites.google.com/site/scientificabilities/. Here we give examples of two activities and explain what reasoning abilities can be assessed using the rubrics.

Example 1:
An elevator is pulled upwards by a cable so that it moves at a constant upward speed. Maria draws the (unlabeled) force diagram for the elevator shown on the right and says, “if the elevator is moving upwards at a constant rate, the forces exerted on it must add to zero.” Jose disagrees. Looking at the force diagram he says “the way you’ve drawn the force diagram, the elevator will stop moving because there is no net force exerted on the elevator.”
a) Correctly label the force diagram (Figure 3).

b) Who do you agree with and why? For the statement you disagree with, how would you convince him/her that he/she is incorrect?

This example helps assess the following scientific abilities: ability to represent the situation with a force diagram, ability to evaluate somebody else’s reasoning, ability to design an experiment to test a hypothesis.

Example 2:
You have a loop of wire connected to an ammeter (shown in Figure 4), and a bar magnet.

![Figure 4. A loop of wire connected to an ammeter.](image)

a) Describe an experiment that will make the ammeter needle deflect to the right. Include a labeled diagram. The needle deflecting to the right indicates the current into the port on the right side of the ammeter.

b) Explain in detail what causes the current in that direction.

This example assesses student ability to design an application experiment and the ability to communicate.

Learning is a social process [10]. The ISLE approach makes socializing and sharing a natural part of student progress. In class students work in groups. As the lab reports require group submissions, they often continue working in groups after the class is over and then start spontaneously forming study groups on their own. As every assignment can be improved, working together does not disadvantage anyone and very quickly the students realize the benefits of collaboration outside of class. Class group work and sharing ideas with the rest and outside of class learning lead to a community of learners. An opportunity to improve one’s work leads to the development of a growth mindset and perseverance. Fixed or growth mindset determine how a person learns and what choices they make in the process. In their work “Mindsets That Promote Resilience: When Students Believe That Personal Characteristics Can Be Developed” [11] the authors show how to help learners develop growth mindset. The ISLE approach is fully consistent with these recommendations. Perseverance is one of the major predictors of success in life [12].

3.3. Key element 3: Need to know and time for telling
As we mentioned above, motivating students to persevere in overcoming difficulties in learning is not easy. While ISLE activities provide intrinsic motivations, research shows that one needs to start with extrinsic motivation to dive deep enough into the material to be motivated intrinsically [13]. To provide extrinsic motivation every unit starts with some “cool” experiment – a real experiment, a video or a historical narrative of a problem. The motivational experiments or problems remain a mystery until the end of the unit but stay a continuous motivation for pushing forward. For example, when students start learning the concepts of electric field, they watch the YouTube by Richard Hammond “car struck by lightning” at https://www.youtube.com/watch?v=ve6XGKZxYxA&t=72s. The video shows a person in the car surviving lightning strikes of enormous power. Why is he safe? The answer to this question comes at the very end of the unit as well as the explanations of any other details in the video that go unnoticed at the beginning.

As we discussed above, while learning physics, ISLE students “invent” or “construct” their own ideas through experimentation and reasoning. Sometimes they arrive to the “accepted” results,
sometime they do not. How do we make sure that the students learn normative scientific understanding and the scientific vocabulary for the concepts that they have just constructed on their own? We call this moment “Time for telling”. The term was coined by Schwartz and Bransford in 1998 in their paper “Time for telling” [14]. “Time for telling” is the moment in the lesson when the teacher summarizes what the students have developed and shares the “normative” information with them (“you just discovered Newton’s third law, this is how it was formalized by physicists”). In a traditional classroom “time for telling” occurs at the beginning of the lesson, when the students are unfamiliar with the phenomenon under investigation and do not have any “need to know”. That is why when we tell students something about an issue they have not grappled with on their own, they do not remember or do not care. In our approach, “time for telling” is a moment when the students can put together their ideas, reflect on them and compare them to what physicists think on the matter. In a similar way, textbook reading comes AFTER the exploration in the class, not before. This approach makes students see where the knowledge in physics comes from – it comes from experimentation and reasoning, not from authority. Only then they go home and read the textbook – we have a special textbook that actually follows this process. However, they read it AFTER they participate in the process themselves.

4. What do ISLE students learn and why is the ISLE approach difficult to implement?

4.1. Student learning and attitudes

Multiple research projects conducted over 20 years showed that students in college and high school who learn physics through the ISLE approach, learn to design their own experiments, collect and represent data, test hypotheses, evaluate assumptions, communicate and evaluate claims ([15]-[19]). They also spontaneously use multiple representations when solving problems [20]. Many start the course not liking the approach but slowly understand the value of it for their current learning and future life ([1], [6], [21]-[23]). Dissertation work of D. Bugge showed that even after 10 years high school students who learned physics through the ISLE approach still remember the reasoning process and apply it when they face a new problem. They also find ISLE-based experience very useful for their college studies and current careers [17].

We found that those students who can explain how they learned certain topic using scientific epistemology achieve better learning gains that those who think that they learned from authority or by doing experiments [24]. The list of publications about students learning through the ISLE approach is numerous, but there are almost no publications about instructors teaching with the ISLE approach. So far, we published one paper describing issues in training the instructors to implement the ISLE approach [25], this work is currently in progress.

However, this short paper about the ISLE approach would be incomplete if we did not discuss why implementing the approach is difficult for instructors. The main issue is relinquishing control. Other issues include facilitating group work and listening to and trusting the students.

4.1.1. Relinquishing control. The role of the teacher in the ISLE approach changes dramatically. The teacher stops being the source of knowledge to transfer to the students but a learning companion who is ready with equipment to test crazy ideas that students come up with. The pace of the class is often controlled by the students working in groups as well as the equipment needed for experiments to test students’ ideas. As the curriculum materials for algebra-level general physics courses have been developed over the years, we have a pretty good knowledge on what “crazy ideas” students come up with trying to explain observational experiments that we designed. But when the students design their own observational or application experiments, they often require new apparatus or they devise new procedures that the instructor needs to be able to help them implement.
4.1.2. **Facilitating group work.** Making groups work efficiently is a very complex skill. We found that mixed abilities groups work better and well a mono-gender groups. White-boards on which the groups present their work are essential – they provide a shared space for collaboration and simultaneously ensure accountability. We often give each student a marker of a different color that that everyone’s contributions are noticed. Some instructors find that the students collaborate better when they share parts of a big board and everyone can cluster together around it. In any case, there has to be time in class when the students share with each other what they found. They can walk around and look at each other boards or they can present their finding to the class. When the groups are working, it is important not to interrupt with guiding questions, but only help when they get stuck.

4.1.3. **Listening to the students and trusting them.** Listening to the students is one of the most difficult skills to develop. When the students are first investigating a phenomenon, they are not familiar with the normative vocabulary, they can express their ideas using the “wrong” words, therefore the instructor needs to listen very carefully not for the right answer and but a good reasoning process. Developing patience and trusting that the students can figure it out without you telling them the right answer is another important but very difficult skill to master. Once we give the answer before students tried all they could to figure it out, we rob them of the opportunity to learn. Patience, trust, and careful listening to what students are trying to say will show you that they are capable of so much more than you expect. Building on student ideas instead of rejecting them is one of the most important features of the ISLE approach.

5. **Summary**
The ISLE approach is a unique methodology of learning and teaching physics that engages students in learning physics by practicing it and empowers them in the process. There is a plethora of curriculum materials developed for teaching introductory physics through the ISLE approach and numerous studies show that students learn physics and learn to think like physicists when they study physics in this environment. Implementing the ISLE approach is challenging and exciting. We invite all readers to try.

6. **Resources to implement the ISLE approach**

1. Etkina E, Brookes D T and Planinsic G 2019 *Investigative Science Learning Environment: When learning physics mirrors doing physics* (Institute of Physics, Concise Publishing; Morgan and Claypool Publishers) DOI 10.1088/2053-2571/ab3ebd
2. Etkina E, Planinsic G and Van Heuvelen A 2019 *College Physics: Explore and Apply* 2nd edition (Pearson)
3. Etkina E, Brookes D T, Planinsic G, and Van Heuvelen A 2019 *The Physics Active Learning Guide (ALG)* 2nd edition (USA: Pearson)
4. Etkina E, Brookes D T, Planinsic G, and Van Heuvelen A 2019 *On-line Active Learning Guide for on-line instruction (OALG)* (USA: Pearson)
5. Etkina, Brookes, Planinsic, and Van Heuvelen 2019 *The Physics Active Learning Guide for on-line instruction (OALG)* (USA: Pearson)

*Links to book websites*

ALG videos: [https://media.pearsoncmg.com/aw/aw_etkina_cp_2/videos/content/alg_users.php](https://media.pearsoncmg.com/aw/aw_etkina_cp_2/videos/content/alg_users.php)

Main text videos: [https://media.pearsoncmg.com/aw/aw_etkina_cp_2/videos/content/videos.php](https://media.pearsoncmg.com/aw/aw_etkina_cp_2/videos/content/videos.php)
6. Community of ISLE users: To participate in the community of users, get access to the latest improvements and other suggestions, join Facebook group “Exploring and Applying Physics” (do not forget to answer the question when you apply).

7. Free ISLE-based curriculum modules (PUM – Physics Union Mathematics) for middle school, Physics First and High school [http://pum.islephysics.net/]

8. A complete ISLE Laboratory Program (for algebra- and calculus-based physics) [https://sites.google.com/site/scientificabilities/]

9. A set of ISLE Video Experiments with questions [http://www.islephysics.net/pt3/]

10. ISLE-based physics video games at [http://www.theuniverseandmore.com]

Contact with ISLE developers
E-mail Eugenia Etkina Eugenia.etkina@gse.rutgers.edu (large enrollment algebra-based classes, high school classes, teacher preparation and professional development);

David Brookes dtbrookes@gmail.com (large enrollment algebra-based classes, small enrollment calculus-based classes in studio format);

Gorazd Planinsic gorazd.planinsic@fmf.uni-lj.si (ISLE-based experimental problems, video problems, advanced ISLE labs).

Paper with specific ISLE-based activities
1. Etkina, E and Planinsic G 2015 Defining and developing “Critical Thinking” through devising and testing multiple explanations of the same phenomenon The Physics Teacher 53 432-437
2. Etkina E and Planinsic G 2014 Light Emitting Diodes: Exploration of Underlying Physics The Physics Teacher 52 4 212-218
3. Planinšič G and Etkina E 2015 Light Emitting Diodes: Exploration of New Physics The Physics Teacher 53 4 212-218
4. Planinšič G and Etkina E 2015 Light-Emitting Diodes: Solving Complex Problems The Physics Teacher 53 5 291-297
5. Faletic S and Planinsic G 2020 Surprising electroscope experiments help students think like physicists Physics Education 55 045017
6. Planinsic G and Etkina E 2019 Mysteries of conductive thread: physics and engineering combined Physics Education 54 045015
7. Planinšič G, Gregoric B and Etkina E 2014 Learning and teaching with a computer scanner Physics Education 49 5 586 - 595
8. Etkina E, Planinšič G and Vollmer M 2013 A simple optics experiment to engage students in scientific inquiry American Journal of Physics 81 11 815-822

7. References:
[1] Brookes D T, Etkina E and Planinsic G (2020) Implementing an epistemologically authentic approach to student-centered inquiry learning Phys. REV. PER. 16 020148
[2] Macmillan C J B and Garrison J W 1988 A Logical Theory of Teaching: Erotetics and Intentionality (Dordrecht: Kluwer Academic Publishers)
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