Interpreting the investigative science learning environment (ISLE) for its implementation in Indonesian STEM education

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Abstract This paper reports a qualitative inquiry to investigate the application of the Investigative Science Learning Environment (ISLE) approach as a framework for teaching and learning physics. The aims of this study are to investigate how ISLE processes are applied, what the perspectives of instructors and students on the ISLE approach are, how the ISLE approach could be possibly applied in the physics courses and other STEM courses in Indonesia. Participants in this inquiry consist of the inventor of ISLE, three ISLE instructors, and students in an ISLE lab session. We used qualitative case study method and narrative data analysis in the process of evaluating data from observations, interviews, and ISLE-based learning materials and publications. It was found that the ISLE approach was applied smoothly in the class and lab sessions. The ISLE instructors are those who believe in the philosophical and epistemological reasoning behind the framework and the importance to nurture students’ scientific abilities. Some students liked the ISLE approach, some didn’t. Those who liked ISLE found that they enjoyed the process of thinking and discussing in learning. It is very likely to apply the ISLE approach in Indonesia for physics courses, but it will be challenging for other subjects.

1. Introduction

The Investigative Science Learning Environment (ISLE) approach is an interactive teaching method that “help students learn physics by engaging in processes that mirror the activities of physicists when they construct and apply knowledge (pp. 1)”\textsuperscript{[1]}. The creator of ISLE is Distinguished Professor Eugenia Etkina from the Graduate School of Education (GSE) of Rutgers, the State University of New Jersey, USA. Her intellectually creative and notable work in developing and implementing ISLE in physics courses has been recognized by the American Association of Physics Teachers (AAPT) that awarded her the 2014 Robert A. Millikan Medal.

Four years ago, we learned about the ISLE approach and its creator from Irwandi who participated in a workshop on ISLE conducted by Prof. Etkina and Prof. Planinsic at the International Center for
Theoretical Physics (ICTP) in Trieste, Italy on January 25-30, 2015. We read several articles about ISLE including Prof. Etkina’s Millikan award lecture: *Students of physics—Listeners, observers, or collaborative participants in physics scientific practices* [2] and her most cited book chapter about ISLE, *Investigative Science Learning Environment – A Science Process Approach to Learning Physics* [1] to understand more about ISLE. Inspired by the learning approach that directs students to mirror how physicists do in constructing physics concepts, Irwandi and Melvina, physics educators from Universitas Syiah Kuala in Aceh, Indonesia, tried to conduct a similar workshop for science teachers in Banda Aceh, Indonesia. The teachers who participated on the workshop loved the approach and suggested that they conduct more workshops on using ISLE for teaching science. Following the call and concerning on Indonesian students’ low achievement in international assessments for science and mathematics (see [3], [4], and [5]), we proposed a research project “Integrating ISLE in Integrated Science Instruction to Improve Science Teachers’ Abilities in STEM Education,” to USAID-PEER Program by asking Prof. Etkina’s support as the USG-partner of our project. Selected as one of projects supported by the USAID-PEER Grants for the years of 2017-2020, our project has implemented some of our proposed programs that can be categorized into four main programs: (1) outreach and collaborations, (2) development of learning resources, (3) development of teachers’ capacity building, and (4) advocacy of STEM education. This project initiated the birth of STEM Research Center at Universitas Syiah Kuala (Unsyiah) that became the first research center in Indonesia focusing on the development of STEM education in Indonesia.

Since the main goal of our project is to integrate ISLE in science instructions, we see the importance to gain firsthand experience about ISLE from scholars who developed it. In June 2018, Assoc. Prof. David Brookes from California State University at Chico, one of Prof. Etkina’s research partners in developing ISLE, gave a workshop on ISLE at Unsyiah in Aceh, the westernmost province of Indonesia. The 5-day workshop was attended by science teachers and educators. Professor Brookes introduced the ISLE processes and participants were directed to observe, explain, observe again, find the pattern, explain, design an experiment, find a pattern, explain, test ideas using experiment, predict the outcome of the testing experiment, revise the explanation if the testing experiment’s result is against the previous explanation, and so on and so forth. The participants were directed to apply the ISLE cycle shown in Figure 1 in learning Physics concepts on DC circuits, LEDs and energy conversions, motion (emphasizing force diagrams), and circular motion [6].

At the end of the workshop, the participants created lesson plans and tried them to groups of high school students from UNSYIAH Lab School. We found that students were engaged actively and were able to follow the lesson and to create the observational experiments, give explanations, and test their explanations by making predictions of the outcomes of the testing experiments that they designed. However, we also found that not all teachers who participated in the workshop understood the ISLE approach properly. Some of the teachers still produced cook-book-type lesson plans, which were not aligned with the spirit of the ISLE approach that expect students to develop their understanding by designing their own experiments and reason from them. We suspected that the five-day workshop on ISLE was not enough for teacher participants to grasp the philosophical and practical ideas of the ISLE approach. Furthermore, the lack of English proficiency also played an important role for the teachers to effectively learn from the workshop that was conducted in English. To ensure that the teachers would develop their understanding and familiarity with ISLE, we need to conduct more workshops for those teachers who are already interested to apply ISLE approach in their teaching.

One of the suggestions given by David Brookes was that due to the lack of English proficiency among the participants of the workshop, in the future, it would be more beneficial if our research team members who are proficient in English received the training first, then after getting the training, we would conduct the workshop for the teachers. This suggestion forced us to learn more about the ISLE approach and how it became a powerful approach for teaching physics. We also have an inquiry whether we can apply ISLE in not just physics courses, but also in other science, technology, engineering, and mathematics (STEM) courses.
We believe that to find the answers for this inquiry, we should be exposed more to the ISLE-based learning experiences. One of our proposed activities on USAID-PEER Project was visiting Prof. Etkina at the Graduate School of Education (GSE) at Rutgers, the State University of New Jersey, USA. We intended to use this opportunity to get other firsthand experiences with the ISLE approach through class observations, interviews, and careful investigation of learning materials and publications about ISLE. This paper is intended to report what we have learned through our observations and interviews and to provide answers to our questions: 1) How are ISLE processes actually applied in the classroom and lab settings?; 2) What are the perspectives of instructors and students to the ISLE approach?; 3) How could ISLE possibly be applied in Indonesian physics courses; and 4) How could ISLE possibly be applied in other STEM courses in Indonesia?

2. Literature review
Historically, the ISLE approach was developed by Eugenia Etkina based on her realization that no matter how well prepared and wonderful presentation and demonstration that she did, as one of the best teachers in the Russian school where she taught, students did not learn much from her. Students remembered the concepts of physics when they learned the concepts on their own. From that point of time of realization, she switched her focus from what she would do to teach her students to what students would do to learn [2]. She developed ISLE after investigating carefully the epistemology of science, brain science, and cognitive psychology in learning science [1]. Her collaboration with A. Van Heuvelen

Figure 1. ISLE Cycle Diagram [2]
enhanced the approach by adding the multiple representation approach to the analysis of physics phenomena.

2.1. ISLE Learning System

The ISLE approach is a structured constructivist approach for learning [1]. Constructivism is based on the beliefs that students actively construct their own knowledge and reality is determined by the experiences of the learners [7] that was rooted from Piaget’s view of individual learning [8]. ISLE is also based on the understanding of the importance of prior knowledge to construct new knowledge. As other constructivist approaches that were influenced by Vigotsky’s sociocultural theory [9] and the abundance of the empirical proof that active learning is much more effective that the traditional lecturing approach, ISLE is a student-centered, inquiry-based, interactive, and cooperative learning approach. Vigotsky’s ideas of the importance of language and scaffolding [10] are also considered important in ISLE ([11], [1]). However, not like other constructivist approaches that lacks of structure [7] and required students to read the concepts that they will learn or elicit their ideas before they did class/lab activities (see [12], [13]), ISLE students are not required to read any sources related to the concepts that they are about to learn, and the teacher will not elicit any predictions before the observational experiments [1].

This pedagogical approach was based on the realization that the practices of assigning pre-reading tasks and eliciting students’ pre-instructional knowledge are not very effective. The practices commonly used in constructivist learning are based on Strike & Posner’s conceptual change theory of learning [14] and are aimed to initiate cognitive conflicts that later will be resolved in a deep engagement in class activities. In constructivist classrooms that use the conceptual change approach, teachers usually ask the students explicitly to predict what would happen in a situation that will raise cognitive conflicts between students’ misconceptions and the correct scientific conception [15]. These practices were considered insufficient to induce change [1]. Arguing that students’ characteristics such as motivation, affective assistance, and beliefs about learning play important roles in inducing changes in learning and that exposing students to repetitive cognitive conflicts might hinder learning due to students’ dissatisfaction on their own misconceptions, ISLE offers a learning environment that is safe for students to explore and express their own ideas [1], without creating negative emotions on students when they make mistakes or expressing their ideas. Furthermore, ISLE also provides non-authoritative climate and students are graded by their own mastery, not by comparing their grades with their peers [1].

One other thing that differentiate ISLE from other constructivist science learning methods is that ISLE consistently applies science processes in its instructions. Even though, there is no consensus on the steps of a scientific method that were conducted by scientists in developing and applying knowledge, there are some elements of scientific processes that most scientists agree on. The elements are empirical data, inductive and hypothetico-deductive reasoning ([16], [17]), logical, reasonable, and testable ideas, and collegiality [1]. Using these elements, ISLE was developed to help students engage in the scientific processes that mimic some of the processes that scientists do in constructing and applying knowledge. Etkina [2] argued that this approach will help students become critical and independent thinkers as physicists who constantly come up with ideas and evaluate those ideas. Etkina sees that developing critical and independent thinking will help students in the future, whether they will become physicists or not [2].

Based on the consideration of the learning theories and scientific epistemology on how scientists construct and apply science that were reflected on how students learn science, Etkina & Van Heuvelen [1] listed the elements of ISLE learning system as below:

- The processes to construct knowledge are fundamental in students’ learning
- Effective collaborative learning is essential, so students always work in group and actively communicate ideas among their group mates.
- As scientists do, students also conduct data collection and analysis and interpret the data analysis results and they also design their own experiments to test ideas and to solve problems.
- Students solve not only traditional physics problems but also complex problems.
Examples on how ISLE was applied in helping students learn physics have been presented in many publications of Ekina and her team, for example, in the lessons of circular motion [1], ray and wave optic [2], motion [18], and projectile motion ([19] & [20]).

2.2. ISLE Processes
When reviewing the examples of ISLE lessons mentioned above (see [1], [2], [18], [19], & [20]) and from our experience from Brooke’s 5-day workshop, it was found that ISLE processes in a conceptual learning unit usually start with observing phenomena. Students are observing phenomena that were carefully selected in the form of simple and clean observational experiments that they performed or watched from demonstrations conducted by the instructor or showed in a video. Students should be able to infer a pattern and make logical explanations about the phenomena. Students can come up with as many explanations as they could think of, however all explanations should only be based on the observations of the phenomena and do not come from students’ intuition or “gut feeling”. They are also encouraged to use as many representations as possible, like drawing the situations, graphing diagrams, use table, equations, etc. Activities to build the abilities to make explanations using multiple representation are important in ISLE. Following A. E. Lawson [17], in testing ideas, all explanations are considered true until they are proven to be false by experiments. To test the explanations, students are encouraged to design testing experiments and while they design the testing experiments, they should take into account some assumptions and think of predictions on what should happen if their explanations are true when they conduct the experiments.

Instructors could assist the students through scaffolding, such as suggesting what testing experiment that student can do to test their explanations, what equipment that could be used in the testing experiment, and providing historical data on how scientists did the testing experiment that could not be conducted in the classroom/lab. Designing the testing experiments is considered as a challenging process in ISLE [21], because we have to test unlimited explanations that students could come up with. It is difficult in face-to-face instruction and it becomes more difficult for online learning. However, Ekina and team have developed quite comprehensive materials that provide several ideas for testing experiments based on common students’ explanations for helping teachers and students to apply ISLE in learning physics (see [22], [23], [24] and [25]).

After conducting testing experiments, students will find that some or all of their explanations are rejected and they should revise their explanations or provide alternative explanations. They could also go back to the observational experiments to gather more data to revise their explanations and then repeat the process of determining assumptions and making predictions for testing experiments. If an explanation cannot be rejected by a testing experiment, then students could design another testing experiment in order to reject the explanation. If the explanation cannot be rejected by many testing experiments, students should realize that the explanation is not necessarily true, but students just failed to reject it. At this stage, students can read the textbook and other learning materials and perform application experiments “to explain new phenomena or to design technical device” ([20], p. 352). These processes are described in a cycle diagram shown in Figure 1.

2.3. ISLE instructional structure and resources
The ISLE approach has been used in introductory physics courses in many universities in the United States of America such as in Ohio State University [26], in Princeton University [27], in Florida International University [28], and of course in Rutgers, the State University of New Jersey [1] where it was initiated. In large enrollment physics courses at universities the ISLE approach can be implemented without changing the traditional setup of “lectures” problems solving sessions and laboratory sessions. In smaller courses, students work in studio settings where there is no distinction between the types of classes and of course, in a high school setting there is no distinction. In large enrollment physics courses with the traditional structure, ISLE renames “lectures” into “large room meetings” to underscore that that there is not much lecturing in ISLE.
In large room meetings students have an opportunity to observe experiments (observational experiments) and work in group of two or three students to develop explanations regarding the physics phenomena that they observed and discuss experiments to test their explanations with assistance from the instructor [1]. In the large room meeting, the students also work to solve problems. Sometimes students conduct observational experiments in labs, before they come to large room meetings. More often, in the lab session students conduct testing experiments and the instructor helps them through scaffolding as well as application experiments and they also solve more complex problems. One other element that is a part of the instructional structure of ISLE is problem solving sessions sometimes called recitations. In the recitations, “students work in groups on problems—qualitative problems, multiple representation activities, and often on more complex multi-part problems ( [1], p. 9).” How the portions of the elements of instructional structure in ISLE for large enrollment physics courses such as large-room meetings, laboratories, and recitations in other universities are allocated depend on the situation and time provision of each course. In some high-schools all activities are conducted in the same room and there is no distinctions between class and lab. The arrangement on how the instructions are structured are varied among the institutions that applied ISLE.

Instructors who want to implement ISLE in physics courses need guidance and supports in doing so. With her many projects including ISLE: Science and Cognition Combined [29] and Physics Union Mathematics (PUM) [30], Etkina and team have conducted more than 150 workshops for physics instructors including physical-science middle-school teachers and physics high-school teachers. In addition to the series of textbooks for university introductory physics courses (e.g. [22], [23], [31], [32], [33]), some modules for middle school science and high school physics have been developed to help teachers and students who learn science, especially physics, using the ISLE Framework [30]. Etkina, Brookes, and team also developed some videos of experiments of physics concepts that won the Science Price for Online Research in Education (SPORE) that was awarded for the Rutgers Physics Teaching Technology Resource (http://islephysics.net/pt3/) in October 2010 by the American Association for the Advancement of Science (AAAS) [34].

2.4. ISLE helps students develop scientific abilities

Professor Etkina believed that the ISLE approach does not only help students develop their conceptual understanding and problem solving skills, but also nurture the development of students scientific abilities that include: abilities to explain phenomena in multiple representation, abilities in designing and conducting observational experiments, abilities in designing and conducting testing experiments, abilities in designing and conducting application experiments, abilities in communicating scientific ideas, abilities in collecting and analyzing data from experiments, and abilities in evaluating models, equations, solutions, and claims ( [2], [35], [36]). The scientific abilities are those that scientists used in creating and applying knowledge in their field [1]. Students’ scientific abilities, their conceptual understanding, and their problems solving skills are assessed by instructors and the students themselves as self-assessment using assessment rubrics and instruments that have been carefully developed. ISLE encourages the use of various assessment tools to evaluate students’ learning

Since in the ISLE framework the assessment of students’ learning not only measures knowledge and problem solving skills, but also students’ scientific abilities, then various assessment tools are used. Some traditional assessment instruments such as the Force Concept Inventory and Conceptual Survey of Electricity and Magnetism are used, but some new developed assessment rubrics are also used (see [2] & [35]). Etkina and Van Heuvelen [1] summarized five aspects of assessments that are used in ISLE framework: 1) Focus not only in assessing students’ knowledge and problem solving skills, but also in assessing students scientific abilities; 2) Focus in providing feedbacks for students in formative assessment; 3) Focus in non-traditional physics problems that combine traditional problems and problems involving multiple representations, evaluations, and designs; 4) Laboratory exams are common in some ISLE courses where students are asked to design and conduct experiments to test ideas, alternative theories, and to solve experimental problems; 5) Students are graded by points that were accumulated since the course started and their exam grades are not compared with their peers’ grades.
Rubric for assessing students’ scientific abilities and other resources for assessments can be found in http://www.islephysics.net/resources.php.

2.5. Teachers’ and students’ perspectives on ISLE and students’ performances

In her Millikan Award lecture [2], Prof. Etkina described what she envisioned of students and teachers’ perspectives on ISLE as a teaching and learning approach. Teachers constantly think about what students will do to come up with concepts in physics. They also see that the process of constructing conceptual understanding is as important as the understanding itself and its application in problem solving. Teachers should allow students to come up with as many explanations as possible and test them systematically and recognize that students’ ideas are very important in this process. Teacher also see the importance of the roles of experiments to help students to: 1) develop models, explanations, and hypothesis; 2) test the models, explanations, and hypothesis; and 3) apply the remaining models after thorough tests have been conducted. Teachers should recognize that students’ explanations do not come from students’ personal intuition and should give the opportunities for students to question their own assumptions. Teachers also encourage students to use multiple representations including language in the reasoning process. Students are not encouraged to read the textbook before they construct and test their new ideas in the interactive experiential learning episodes.

For students, learning in the ISLE framework means they will continuously ask themselves on how they learn what they know. They will develop the skills of observing and imagining and they will use their imagination, prior knowledge, and daily experiences to generate explanations of phenomena in physics. Students will use multiple representations to explain a certain phenomenon and they will design and use experiments to test their explanations. They will not be afraid to come up with “crazy” ideas and make mistakes, and they will get used to work collaboratively, communicate ideas with others, and listening to others’ ideas. In measuring ISLE students’ ideas of experimental physics, including their beliefs, attitudes, and expectations about the nature and importance of experimental physics, some studies used the Colorado Learning Attitudes about Science Survey for Experimental Physics (E-CLASS) [37]. When comparing students’ E-CLASS scores between those who learn in traditional physics courses and those who learn in experiential learning environment including ISLE, studies found that students’ pre-instruction scores of both groups are similar, meanwhile the post-instruction scores of the students in the traditional courses are significantly lower than their counterpart’s scores. This means, ISLE students value experimental physics in learning more highly than traditional-course students.

Using traditional assessment instruments and interviews to compare students’ physics knowledge and their abilities to explain how they learned the knowledge, it was found that ISLE students performed better in traditional physics tests, but they also possess the ability to articulate the learning processes that they experienced comparing to their counterpart [2]. Learning of the 20 years of development of ISLE to be a recognized, well-structured, and resource-rich learning environment that is adopted by many physics and science educators we wonder if we can apply ISLE in Indonesia. Learning that Indonesian students’ performances in international assessments are not quite satisfying until recently (see [5], [4], [38], [39], [40]), that force the Indonesian government and educators to reform the curriculum and teaching practices especially for STEM courses in Indonesia, we see the opportunity to apply ISLE in STEM education in Indonesia. In the following section we will review the development of K-12 Indonesian national curriculum and teaching practices for mathematics and science.

2.6. Teaching and Learning of STEM in Indonesian context

The development of education and national curriculum for science and mathematics in Indonesia from the colonized era until recently, have been summarized densely in [39] and [40] that provided perspectives on the nature of Indonesian education system, especially for the development of K-12 science and mathematics national curriculum. In the papers, the poor performance of Indonesian students in science is also discussed. Indonesian government has initiated many efforts in reforming education system in Indonesia by increasing the compulsory education from 9 to 12 years, increasing budget for education up to 20% of the national budget, decentralizing the primary and middle school
level, improving the quality of teacher preparation programs, increasing teachers’ salary based on performances through teacher certification programs, providing teacher professional development, and improving the national curriculum ([39], [41]). There is hope that the new national curriculum known as 2013 curriculum, will help to improve students’ performance in international assessments, to prepare students to enter the work world, and to increase students’ awareness of socio-cultural and environmental issues [39] (see [42] and [43] for an overview of the curriculum). However, there are many critics that Curriculum 2013 were developed without appropriate need assessments and put too much burden to school administrators and teachers that hinder them to focus on the quality of instructions, in addition to the lack of readiness of schools and teachers to implement the curriculum ([40], [44]). In the midst of controversy regarding the problems faced in the implementation of Curriculum 2013, in 2014, the Ministry of Education and Culture terminated the curriculum for revisions. The revised curriculum was implemented again in 2018.

The most recent change on Indonesian curriculum was due to Covid-19 pandemic that led the Minister of Education and Culture issued the Decree of the Minister of Education and Culture No. 719/P/2020 regarding Curriculum Implementation Guidelines on Education Units in Special Conditions or known as Emergency Curriculum on August 4, 2020 [45]. The implementation of the Emergency Curriculum aims to provide flexibility for all educational units in all levels of education to determine the curriculum they used based on students’ need in learning. Education units could choose three options: 1) to still use the Current National Curriculum; 2) to use the emergency curriculum; or 3) to simplify the curriculum independently. This flexibility provides an opportunity to apply reformed teaching approach such as ISLE in STEM-related courses. It is difficult to find the literatures that provide robust analysis on the practices of teaching and learning science and mathematics in Indonesia. Faisal and Martin [39] found that among 402 combine years of publications of seven top-ranked science education journals, only 16 titles with addition 2 abstracts that include the word “Indonesia.” Therefore, there are not many robust empirical analyses of the practices of science and mathematics learning and teaching in Indonesia that we can review. Meanwhile, the focus of teaching science and mathematics in Indonesia has shifted to the integration of teaching science, technology, engineering, and mathematics (STEM) [46].

Looking at the development of STEM education in Indonesia, we can trace back to the reformation of the national curriculum. The teaching of integrative science has been the focus on the revised 2013 national curriculum for elementary and middle school level [47]. In elementary schools, science, including physics, biology, and chemistry are taught as integrated subject with social science and mathematics. Meanwhile in high-school, biology, physics, and chemistry are offered as elective subjects. Reflecting on Indonesian students’ achievements in science and mathematics, there is a prediction that Indonesian teachers’ content knowledge for teaching science and mathematics, let alone the integrated STEM subjects, is weak ([39], [40] [46]). The application of teacher-centered teaching practices and lack of students’ engagement in learning science and mathematics are considered as the culprit of students’ low performances in science and mathematics, or STEM in general ([40], [48], [46]). Based on our observations, very few science courses at schools that apply experiential learning in their instructions. Many laboratories at schools are dusty because they are abandoned for the whole school years, students never learn anything there. Teaching science using experiments faced many challenges, including the lack of skills of teachers in conducting experiments in their instructions [49]. It is compulsory to provide workshops for teachers to apply ISLE in STEM Education.

3. Methodology
To remind us to the inquiries that we try to answers, here are the research questions of this study: 1) How are ISLE processes actually applied in the classroom and lab settings?; 2) What are the perspectives of instructors and students on the ISLE approach?; 3) How could ISLE possibly be applied in Indonesian Physics courses; and 4) How could ISLE possibly be applied in other STEM courses? We apply a case study approach in investigating ISLE and instructional practices in STEM education in Indonesia to assess the plausibility to apply ISLE in Indonesian STEM courses. In collecting data, we observed 2
large class meetings and 2 lab sessions of an Introductory Physics course at Rutgers, the state university of New Jersey, we also conducted 8 interview sessions with: 1) the inventor of ISLE, 2) three instructors who teach using the ISLE framework consisting of an instructor who have used the ISLE approach for more than 15 years who are also one of the authors of the College Physics textbook [32] who we considered as an expert ISLE instructor, and two other instructors who apply ISLE for about five years in different universities, and 3) Four ISLE students interviewed briefly during two laboratory sessions. We also reviewed more than 20 research articles on the philosophical background and implementations of ISLE in science courses and analyzed the ISLE learning resources including the three textbooks and ISLE videos ([24], [22], [23], [25]). For Indonesian educational contexts, we used our own observations of instructional practices in Indonesia and analyzed the literature on Indonesian educational issues in STEM education. The data were analyzed qualitatively using narrative analysis method to find the answers for the research questions.

4. Results
4.1. ISLE in Practice
In the first day of our visit to GSE we discussed with Prof. Etkina about how an instructor applies ISLE cycle in a lesson. We clarified our understanding about the cycle that we have learned from many sources (e.g. ISLE cycle follows the process that physicists do to construct certain concepts and laws). First, scientists observed some phenomena that occurred in the real life that are represented by the observational experiments. Eugenia explained that teachers could set up the observational experiments, but students can also conduct their own observational experiments. As an example how a unit works, she showed an example how the Chapter 5 about Circular Motion in the Active Learning Guide is delivered. She showed us the guidance activities that can be shown in figure 2. It is possible that this unit starts in a class meeting or in the lab session. If the unit starts in the class setting, the instructor can perform the activity and the students observe, but if this unit starts in the lab session, students can perform the activities with other students in their group. So, it does not matter who performed the observational experiments. Eugenia also mentioned that it is possible that in the class setting the instructor shows the video of the observational experiments. The Active Learning Guide helps instructors to determine which observational experiments that are vital for students to observe in starting the ISLE process of each particular unit. The Active Learning Guide also helps instructors to choose activities that they can do in the class or lab setting. We also found that the observational experiments are very simple and “clean” in terms of there are not many factors involve in “the system of objects moving in a circular motion.”

After carefully observe the phenomena occurred in observational experiments, students are expected to make explanations about the phenomena they observed. Using Etkina’s words, any “crazy” explanations are welcomed. ISLE encourages students to use multiple representations in explaining the phenomena. They could use mathematical representations in term of equations, formulas, and graphical representations (such as force diagrams). They also could use table, bar graphs, and other representations to explain the data they collected from the observational experiments. After making explanations based on the phenomenon they observed, students discussed with their group the design of testing experiments. What we observed in an undergraduate algebra-based Introductory Physics Lab at Rutgers University was 8 groups of students (4 students in each group) write their explanations on small white boards about the phenomena they observed from a video of an observational experiment. Students worked in a circular table and they can move freely in the lab and saw what other groups did. They also can take the equipment they need from the equipment table in the middle of the lab. All group worked on Chapter 3 Newtonian Mechanics (section 3.8 Forces come in pairs: Newton’s third law) in the Active Learning Guide. In this section, students seemed were not too familiar with the force diagram (one of common representations in ISLE). We witnessed the first force diagram that a group of students made that correctly describe the physical phenomenon they observed after several fail attempts. We can sense the feeling of accomplishment that the students showed after they finally succeeded drawing the force diagram.
5.1.1 Observe and find a pattern

**PIVOTAL Lab or class:** Equipment per group: Bowling ball, mallet, backpack or bucket, rope or strong string

Together with your group, perform or observe the following three experiments. For each experiment, fill in the blanks in the table that follows.

a. Let one person in your group roll a bowling ball along a smooth floor. As the ball moves, tap it with a rubber mallet, trying to make it move in a circle. In what direction did you need to tap to make it move in a circle?

b. Swing a bucket attached to a rope and filled with water or sand at constant speed in a horizontal circle.

![Figure 2](image_url)

**Figure 2.** The Active Learning Guide’s Instruction for Conducting Observational Experiments [22]

If we connect the experience that the students had with the scientific abilities that ISLE targeted, in the particular lab session and for those particular students, their abilities to explain the phenomenon using multiple representation have been nurtured. We did not see any students who tried to copy other groups’ explanations. Since all ideas are assumed to be temporarily true, then to test an idea, the students have to design an experiment and make a prediction what would happen if the idea is true. There was no rushing in getting the predictions right. One group of students wrote five explanations on the board and they discussed how to design experiments to test the explanations. The instructor in the lab session helped them in designing the experiments by suggesting the students to predict what would happen if an explanation is true if they conducted the experiment, so the students realized that their experiments should be able to help them find whether their explanations are supported by the data or not. Sometime the discussions are only among the instructor and a group of students, but if the instructor found that similar issues are faced by several groups then the instructor started to call all students’ attentions to have a whole lab discussion.

We observed that students designed their own testing experiments on *Force come in pairs: Newton’s third law*, where they design various experiments where two objects exert force to one another. They measured the force exerted by object A to object B and also the force exerted by object B to object A. They found that, no matter how they design the characteristics of the objects such as a big object versus a small object, a heavy object versus a light one etc., the forces of the objects exerted to one another are always the same. Most of the groups came up with the explanations that bigger or heavier objects exerts larger force. Then they designed experiments where two objects with different sizes or different masses exert forces to each other. Most of the groups thought that the forces would be different. They used force
gauges that were connected to computers so they can see the forces exerted by the objects on the monitor. Some students predicted that the forces should be equal and failed to reject the prediction. Prof. Michael J. Gentile, the instructor who was also a co-author of the first edition of the textbook used in all ISLE-based physics courses [31], explained to us as the observers that in the testing experiments students will find that the forces exerted from object A to object B and one exerted from object B to object A are always equal regardless of the characteristics of the objects. Later, in the large room meeting, Prof. Gentile will lead a class discussion on Newton’s third law.

One important aspect emphasizing by ISLE is that students should work collaboratively. Either in a large classroom setting or in a lab that has fewer students, group work is always recommended. Even in a large room setting, students are encouraged to work in pairs. Think-Pair-Share is one of a common strategy used in a large room setting that applies ISLE. We observed that the classroom was noisy from time to time while the Think Pair Share activities were ongoing, but when the instructor talked, all students paid attention and you can only hear the voice of the instructor. Even though most of the students engaged actively in the lecture and lab, few hesitant students were observed during the Think Pair Share activities and the lab. However, when we interviewed some students who looked hesitant, we found that they were not comfortable with this untraditional approach that took longer time to complete, but they understood that the purpose of the approach is to help them learn physics by constructing their own understanding. However, they were more comfortable with the cook-book type of lab instruction where they could complete the task in a shorter time without getting confused from time to time. In our observations, the hesitant students still did their job engaging in group activities. We observed some students who really liked the approach and with smiles on their faces explained that they liked the lab very much because the activities made them think about the physics concepts and understand the concepts through discussion and experiments. We saw some students’ eyes lighted up when they found that their predictions were confirmed or they found something interesting from the experiments. When we interviewed the students two of them are from Biology major and the other two were majoring in Business and Communication. Prof. Gentile was always ready to discuss the experiments with the students. In the discussion, Prof Gentile did not give the answers to the tasks assigned to the students. He tended to lead the discussions so that students confirmed their own understanding or ideas. The lab was organized in a way that students and instructor could move easily across the classroom, the experiment tables, and the equipment tables. The safe environment to have different perspectives, the use of round table that implies no hierarchy, and the use of Google Docs to write their group tasks make the collaboration effective.

Observing the classroom and lab in an ISLE-based introductory physics course gave us a better understanding of the approach. Now, the purposes of observational experiments are clear for us. Students seek a pattern based on the observational experiment(s). No prediction made beforehand. Predictions that are based on intuition should be avoided. In her word, Prof. Etkina said, “predictions based on intuition are bad.” Prof. Etkina emphasized that students should make prediction using the explanations that they constructed of the observed experiments (observational experiments). We observed and analyzed that the observational experiments in the Active Learning Guide and videos were carefully crafted so that the physical phenomena that students need to observe were simple and not “contaminated” by “noises” of other physical concepts. Prof. Etkina has a term for this kind of observational experiments, she called them as “clean” observational experiments. Prof. Etkina mentioned that it took her with collaborators over 13 years to develop the first edition of the ISLE-based textbook. The Active Learning Guide in its current form underwent three editions and several people contributed. The main collaborator was Alan Van Heuvelen, with the help of Michael Gentile, David Brookes and Gorazd Planinsic. As mentioned by Prof. Etkina in her Millikan Award Lecture, one of the biggest challenges that ISLE instructors face in the class or lab is to come up with various designs of testing experiments to test students’ unlimited possibilities of explanations. We found that in the Instructor Guide, some common explanations are cited and the testing experiments were set up for the students in the Active Learning Guide. This will help instructors to prepare ideas of testing experiments.
The ISLE instructors should possess the scientific abilities that scientists have. Workshops and professional developments play crucial roles in developing that abilities in ISLE instructors’ skill domain. When we tried to identify the characteristics of instructors to apply ISLE in their instructions, we conducted interviews with Prof. Etkina, Prof. Gentile, Joshua Rutberg, a PhD student who is also a physics instructor at Rutgers University Newark. In addition, we also made an online interview with Prof. Carolyn Sealfon from the University of Toronto, Canada who has been using ISLE in her Introductory Physics since her appointment as the Associate Director of Science Education at Princeton University. We found that the most important characteristic that all ISLE instructors must have is the instructor’s attitudes towards students, not just the skills. In the sub-codes of instructor attitudes we found such example of instructor positive attitude, as providing opportunity for students to resubmit revised work because the instructors believe that each student can improve, opposed to the belief that students will just stay as they are. From our interview with Prof. Etkina and Prof. Sealfon, we found that, the important equipment used in ISLE labs is the whiteboard where students can write/draw their explanations and the lab instructors can easily evaluate and grade students’ work on the board. Using the scientific abilities rubric that only grade students’ work for four categories grades (missing, inadequate, need some improvement, and adequate), this assessment approach will make it possible for the students to revise their work until they get the concept right. Instead of having to evaluate students’ work after lab session that will consume much time, the instructors can assess their students’ work formatively on the spot.

We found that instructors’ beliefs in the philosophical view of the instructional reform played an important role in their commitment to apply the ISLE approach in their teaching. These beliefs are clear from their attitudes towards teaching. All instructors that we interviewed firmly believe that traditional ‘lecturing’ approach in teaching science does not help students in learning and that they should nurture students’ scientific abilities during their learning. Three of them mentioned that science learning should be set in an environment that is safe and encouraging. The practice of eliciting prediction before students do the activities will make them feel awful (using the exact word used by an instructor we interviewed), because their predictions are usually wrong. Students will develop feeling incapable in doing science. They also believe that the processes in getting the understanding is much more beneficial for students than the abilities to recall science concepts. All the instructors used the activities in the Active Learning Guide in their teaching or, depending on the equipment available, they also improvised some activities from the Active Learning Guide. One more characteristic of the ISLE instructor is that they are firm believers on covering all contents in the curriculum is less important than ensuring that students have the abilities to think critically and know how to learn. They believe, if the students have all the tools to learn, then they can learn all material by themselves. Many teachers and educators are worried more on whether they are able to cover all materials mandated by the curriculum than on whether their students are actually learn on their courses. From our interviews, we found that Rutgers University and the University of Toronto have large enrollment courses of algebra-based Introductory physics courses. In Rutgers University, there are three 50-minutes lectures (large room meetings), a 2-3 hours lab sessions, and two an hour-recitation sessions that students should attend weekly. In the University of Toronto and Rutgers University at Newark all instructors used ISLE textbooks, but whether the instructors apply ISLE in their instructions is depend on the instructors. As many reformed approaches, there are always instructors who resist and continue their traditional teaching approach.

4.2. ISLE in Indonesian Context

With our developing understanding of ISLE framework, we conducted several Focus Group Discussion to introduce ISLE and to see whether we can embed ISLE in our national curriculum (see [50]). We found that, STEM teachers and educators in Aceh, Indonesia are welcome to implement ISLE in their teaching as long as they have supports in doing so. They also see the possibilities to embed ISLE framework in STEM-related subjects in the national curriculum. We also have tried to apply ISLE for middle-school science lessons as well as high-school science lessons (see [51], [52], [53], [54]), and even though the lessons are not quite following the ISLE practices (we realized that after learning about
ISLE more intensely), we see the opportunities to apply ISLE in science courses for K-20 education, especially for the physics course. The ideas of experiential and active learning have been accepted widely among the teachers and educators in Indonesia, even though many teachers and educators did not actually practice the learning approach that they verbally accepted. If Prof. Etkina has been developing ISLE for about 20 years in her career as a physics educator, we, in Indonesia, who believe in inquiry-based interactive learning approach to help students construct their knowledge, have a long time to go. However, what Prof. Etkina has developed will make our efforts will be much easier, especially for introductory physics courses.

4.3. ISLE for STEM Education

We asked Prof. Etkina about the possibilities to apply ISLE in other STEM subjects. Prof. Etkina was certain that ISLE can be applied to other science subjects as long as we understand the history how a scientific concept was developed. If we know how a chemistry concept was developed, then we can design an observational experiments that mirror how a chemist observed a similar phenomenon in the past. We gather more data to seek pattern and come up with some explanations regarding the phenomenon and continue the ISLE processes. The key aspect that we should have is understanding how the chemistry concept was developed in the past. The history. In term of STEM education, the integration of science (physics), technology, engineering, and mathematics has been evidenced in all ISLE lessons that we observed in ISLE textbooks and labs. If we relate ISLE with the trends in STEM education research that combine physics and biology or chemistry to solve real-world problems, the connection can be explained only at the stage when students design and conduct application experiments. Did scientists integrate the processes of creating knowledge in physics, biology and chemistry? We know there are many multidisciplinary scientists in the past. How did they create knowledge in one discipline of science? Was it by integrating the knowledge of multidiscipline or a concept in physics was developed solitary, separated from other subject’s epistemology? We need to explore historical development of science concepts for all disciplines.

Conclusion

ISLE is a constructivist, student-centered, inquiry-based, and interactive approach for learning physics that mirrors what physicists did in creating and applying knowledge. The aims of ISLE are not only for helping students understand the physics concepts that they learned, but also and more importantly for helping students develop their scientific abilities. Some students liked the learning approach because the activities made them think about the physics concepts and understand the concepts through discussion and experiments. Some students were not comfortable with ISLE labs and activities because it took more time and making explanations and designing experiments were confusing. The learning material is well developed and critical in assuring that the ISLE processes can be smoothly applied in class/labs, however, we found that a novice instructor needs training to apply the ISLE methodology. Getting the skills to apply the ISLE approach in physics instruction can be achieved by all instructors who attend a series of ISLE workshops, but what is crucial for an ISLE instructor is their attitudes. The characteristics of ISLE instructors that we observed include that they do not believe traditional lecturing approach works in teaching science, they are also firm believers of the effectiveness of teaching science using experiments and reasoning, they believe that developing scientific abilities are important (if not more important) than memorizing science concepts without experiencing the processes of re-creating the concepts. The ISLE instructors also believe that all students can improve, so they did not grade students using a curve. Students are graded based on their development of competence only and they are not compared with their peers’ competence. The instructors also believe that students should have pleasant learning experiences to actually learn. What will be found difficult in applying ISLE is in designing and applying testing experiments to test students’ unlimited possible explanations on the spot. In Active Learning Guide, Prof. Etkina and collaborators provided some common explanations from students and it is more convenience for instructors to suggest the testing experiments that are appropriate. It is very promising to adopt ISLE in Physics courses in Indonesia, however more trainings for teachers and
instructors are needed. The application of the ISLE framework to other science subjects depends on the willingness of the science educators to learn the history of the development of concepts in each subject. Applying ISLE in integrated science subjects in STEM education is more likely only at the application experiment stage. However, the ISLE approach shows promise in the integration of science (physics), technology, engineering, and mathematics in all units of learning.

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Acknowledgment

Authors would like to express our thanks to Eugenia Etkina, David T. Brookes, Michael Gentile, Joshua Rutberg, Carolyn Sealfon, Gorazd Planinsic, and students in the Introductory Physics course at Rutgers University who have been willing to be observed and interviewed to provide data and support our efforts to understand ISLE. This study is funded by the NAS and USAID under the USAID Prime Award Number AID-OAA-A-11-00012, and that any opinions, findings, conclusion, or recommendations stated in the article are from the author only, and do not always reflect the view of USAID or NAS.