Forefronts of Research Educational Modules

June 20–21, 2016

Workshop Report

Prepared By

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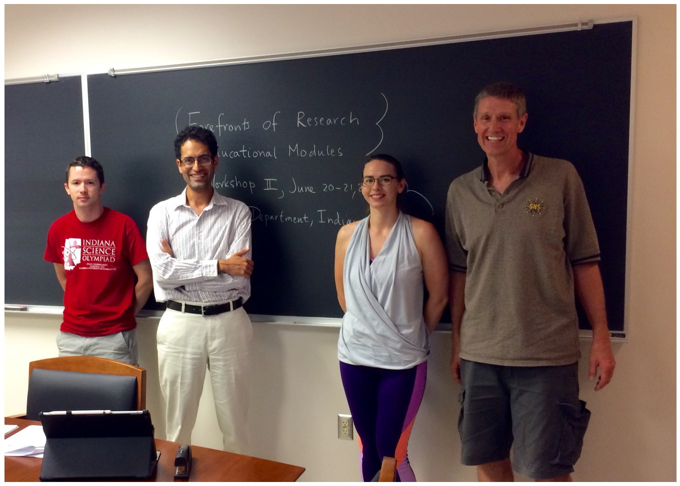

Left to right: Kyle Hagner, Babak Seradjeh, Corrine Deagan, John Calhoun.
Venue: Indiana University Department of Physics, Swain West Hall 236.

June 20, 2016 (Day 1)

The first day of the workshop was mostly focused on general aspects and best practices for (guided inquiry) high school science teaching.

Babak Seradjeh started out with an introduction to project FOREM, its aims and goals. Babak also provided a brief report of the first workshop on June 1-2, 2016 and information shared by the participants, in particular the research findings of Prof. Adam Maltese on student engagement and interest. Different levels of interest (situational, maintained, and individual) were discussed. It was noted that, according to this work, the closer to college people had started to be interested in STEM subjects, the more likely they were to pursue a STEM degree in college. This underscores the importance of student engagement and active learning in high school, since these methods are more likely to spark the students' interest in the subject.

High school inquiry-based science teaching

John Calhoun teaches physics and chemistry at Salem High School, with class sizes of about 15-20 students. He has been teaching for over 25 years and uses hands-on, inquiry-based methods that utilize labs and other activities in his classes. One of the reasons some of his students take physics, John said, is the dual credit they earn based on the AP curriculum for college. While following guidelines and state standards, he said he does not teach to the test.

Kyle Hagner is a graduate student in physics who is involved in the Foundations of Mathematics and Science program at Indiana University.[1] He was initially interested in physics through his interest in math and stumbling upon Carl Sagan's videos on YouTube in college. In his experience teaching undergraduate courses, he said he encounters many students who "hate physics" because it is taught basically as a math course.

Corrine Deagan is a graduate student in biophysics. In high school she took physics with Joe Santonacita (who participated in our first workshop) and referred us to him in a chance conversation earlier in the year. She confirmed that many undergraduates find themselves bored at the topic and do not find it relegated to their chosen career paths. When she was at Rutgers, she reported, that an experience starting with the question "how does brain work as a circuit?" produced a lot of interest in students, who wrote long essays about it.

John offered his perspective on inquiry-based activities. In his classes, students come in with two main backgrounds of living in the city or in the more rural areas; this variety makes it difficult to relate the subject to students based on personal anecdotes. Earlier, Kyle has mentioned how one of his high school teachers always drew on analogies with sports, which he could not relate to. John observed that this is even more challenging in a more diverse class. He noted that the inquiry-based activities and the experience of building things or doing projects individually or in a team provide a better, more uniform context for the students to relate to the subject. It also provides the teacher the opportunity to get to know the students without high-stake testing. Corrine agreed that in her experience kids are held back from true inquiry because of high-stakes test and for fear of getting things wrong.

On the subject of career paths, a discussion ensued on the stereotypical "image" of a scientist. Some participants lamented the stereotypes of a scientist that are propagated through shows like *The Big Bang Theory*. It was pointed out by several participants that to make science relevant to students, it would be helpful to show them who is and can be a scientist. This can be done, for example, by inviting real scientists to the classroom. It was also suggested to point out celebrities who have advanced science degrees, such as Brian May, guitarist for the rock band *Queen* who recently earned a PhD in astrophysics from Imperial College. (Incidentally, in a search done after the workshop,[2] I found that Mayim Bialik, the actress playing the role of Dr. Amy Farrah Fowler in *The Big Bang Theory,* holds a PhD in neuroscience from UCLA.) John related his experience of taking chemistry students to the local water treatment plant, which employs a variety of people with degrees ranging from high school to PhD.

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[1] http://www.indiana.edu/~fsm, accessed on June 24, 2016.

[2] http://goo.gl/NZ9xNl, accessed on June 24, 2016.

High school inquiry-based science teaching

A good portion of the discussion on inquiry-based teaching revolved around how to deal with "wrong" answers. This was earlier identified as a roadblock to participation and learning in the class, especially when inquiry-based methods are used. Several ideas were discussed, including setting expectations at the start and reinforcing them through practice; avoiding too much structure and the emphasis on getting the "right" answer; and conveying the message that "scientists are not authorities."

Some discussion of tools and methods was conducted. John offered his strategies of using hands-on activities and showing videos and introducing vocabulary at the start of a unit, followed by on-board example, and a rotation of activities and discussion. He also uses computer simulations such PhETs. Sometimes, he shows a YouTube video on mute and asked the students to describe what is going on. On the methods, it was agreed that our lesson plans should anticipate, to the extend possible, different kind of responses the students might have and provide the teacher with questions to ask to to sustain the inquiry.

June 21, 2016 (Day 2)

The topic of first modules

From the first workshop, a list of potential topics for the first modules had been drawn up. This list was further discussed with the participants. The list included

More concrete topics:	*More general/abstract:*
LEDs;	Symmetry;
Wireless power transmission;	Space travel;
GPS;	Quantum information;
Scales of motion.	

Mostly on John's request, Babak provided his perspective on several of these subjects.

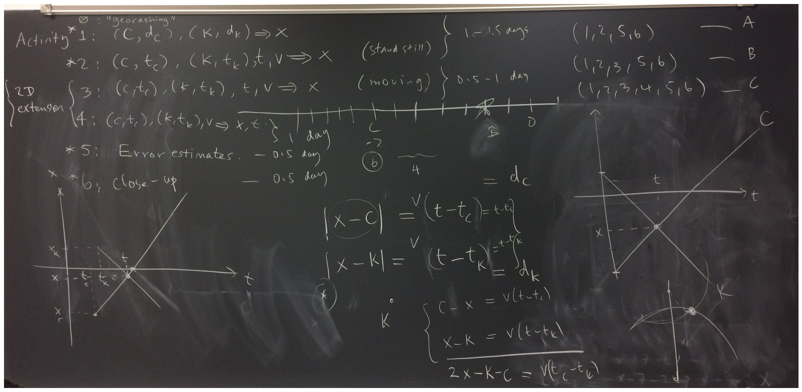
Symmetry is an old concept which has found its way as a cornerstone of modern understanding in physics. For example, conservation laws (conservation of energy, momentum, angular momentum) can be understood as consequences of certain symmetries. As such, as long as our theories have those symmetries embedded in them, we can expect to have the corresponding conservation laws regardless of other details of the theory. Indeed, our physical theories have changed significantly over the past few centuries, going from Newton's theory of motion to Einsteins theory of relativity and then quantum theory. However, all along we have found that conservation of energy and momentum are valid. This is so because, for example, conservation of energy is a consequence of the symmetry in time translation: if a certain motion occurs due to fields of interaction today, it will happen again in the same way under the same fields tomorrow. This view of conservation laws based on asymmetry principle elevates their status to more than just a book keeping device that hinges upon the details of the theory.

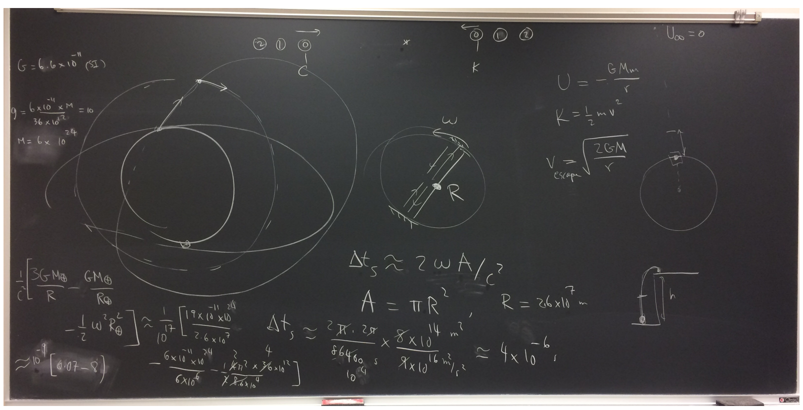
Symmetry is also important in our understanding of various phases of matter. In the 20th century, a new paradigm of understanding phases of matter (such as the gas, liquid, and solid phases of water) was developed based on symmetries of these phases. In the liquid form, for example, the arrangements of water molecules are homogenous and isotopic. In their solid form, however, a translation in space or a rotation around an axis does not bring back the structure to its original configuration. Based on this symmetry principle, a qualitative and even a quantitative understanding can be constructed that accounts for some important properties of liquids and solids, such as the existence of transverse sound waves in the solid, which are absent in the liquid (and gaseous) phase.

Babak demonstrated a few simple ideas of activities and challenges to discuss symmetry. For example, it is easy to see that if you turn an object around an axis by 360 degrees it will come back to itself. However, this simple rotational symmetry breaks down for an object attached to a string. Demonstrate with a cup held on one's palm, one can show a sequence of two 360-degree rotations that take the cup under and over one's arm (the "string") to return the cup and the arm back to their original configuration. This demonstration shows the rotational symmetry of space can be brown to be a rotation by 720 degrees, which is indeed what happens for electrons due to their intrinsic quantum spin. Confining such objects to a two-dimensional plane, for example a ball attached to a strong pinned to a nail, one can even show that all rotations of *n* times 360 degrees are different from each other because the string keeps winding around the nail. This sort of structure become important for electrons moving in a plane and is the cause of various interesting physical effects.

Quantum information is another topic at the forefront of research today, which has inspired many researchers and young scientists in the last 2 or 3 decades, with quantum technologies heralded in the news as the next big transformation in our society. Quantum information relies on the quantum properties of matter, such as the intrinsic spin of particles, to perform multiple parallel computations at the same time. The spin of an electron, when measures around an axis, is always either clockwise or anti-clockwise. This can be used to encode a "0" (say, clockwise) or "1" (say, anti-clockwise). However, when not measured, electrons can be in a combination, or *superposition*, of these two states. Thus many more configurations are possible, which are mathematically equivalent to having two continuous angles to use. This enlarged parallel possibilities is what quantum computers aim to harness to greater efficiency and computational power.

John expressed interest in these topics, but eventually it was decided that these topics may be too abstract initially to pilot in project FOREM. After some further discussion, the group converged on GPS as the topic of the next module. A search for lesson plans yielded only one useful source.[3]





Module 2: GPS (Blueprint)

The basic principle of positioning and concepts needed for the GPS to work will be learned. This will be done in a gradual manner in increasing order of complexity. The starting point will be positioning on a line (one dimension). Extensions to two and three dimensions can be included in the lesson plan.

In the following we will use the following basic data to guide our description. In order to locate the position and time of an event, one needs several signals sent from sources (reference points; satellites) with known location and time stamps. In one dimension, two quantities, (x, t), need to be determined. Thus, we need two sources with known quantities (x_C, t_C) and (x_K, t_K). Knowing the speed of the signal, v, we can then set up the two equations:

$$|x - x_C| = v\,(t - t_C),$$

[3] https://www.ion.org/outreach/lesson-plans.cfm, accessed on June 24, 2016.

$$|x - x_K| = v\,(t - t_K),$$

which simply indicate the distance from the two sources at the time the two signals are coincidentally received. One can then solve for x and t. Instead of the algebraic method, visual and geometric solutions can be found and may be easier for students.

Material and supplies:

+ GPS devices (for geocaching, not essential)

+ strings, several meters

+ tape measure to mark distance

+ a device to measure speed (could be a smartphone app)

Activity 0: Geocaching

This activity is used to set a common stage for all the students, regardless of their experience of using a GPS device. It is, however, expected that many students are already familiar with GPS and finding locations, directions, using online and smartphone maps.

Students are given GPS devices individually or in groups. They will load mapping data and asked to walk in an open area and find previously hidden items at specific locations. They will also record their position.

Lesson 1 – Positioning

Form groups of three students standing on a single line. One GPS student will be asked to find his/her position using the signal received from the other two.

Activity 1:

The two signal students will walk the line to the GPS student and tell him/her the distance they have walked and where they started. using this information, the GPS student can determine where he/she is located.

Activity 2:

In the previous activity, the information about the speed of the signal was not needed since distance was directly communicated to the GPS student. In reality we do not know the distance as it has to be measured independently. Instead we have a known speed of signal (in the real GPS it is the speed of light).

In this second activity, the two signal students walk at a constant pace at a known speed (can be set to, say, 1 meters per second). All students measure their own time. The signal students announce their position and the *time* they started from their original position. The GOS student measures his/her own time on a watch and uses this information and the speed of the students to locate his/her position.

Activity 3:

In The previous activities, the GPS student is stationary. In real applications, the GOS may be moving, so if the signals are not received at the *same time* they cannot be used to find the location. This will be shown first by repeating the previous activity with a slowly moving GPS student. The calculation will to work as before.

In this activity, the students are grouped in 5 or 6 with several signal students. One student will be a recorder (the actual GPS device) who would record when two coincident signals arrive. Then the GPS student will use the information as in Activity 2 to locate his/her position.

Activity 4:

in previous activities the GPS student measured his/her own time on a watch synced to the signal student watches. In real applications, this synchronization may not be available. However, the GPS signal information is sufficient to find our time as well as location. In this activity, the students are arranged as in Activity 4, but the GPS student will not have a watch.

A visual solution can be discussed for the previous activities in terms of x vs. t plots shown in the picture. Once this solution is understood, students can use it to solve the equations geometrically or algebraically.

Activity 5: Error estimates

An important part of the GPS technology is its accuracy. These days, a typical GPS device can locate potion to within a few meters. This level of accuracy requires precise time keeping capability: since the speed of light is so large, an error of only a nanosecond can lead to an inaccuracy of about 0.5 meter. Thus, accurate atomic clocks are used on GPS satellites. Atomic clocks were built and are still perfected today thanks to work on atomic physics and quantum optics with accuracies of better than a picosecond per year. Moreover, certain systematic errors can accumulate and need to be corrected in order for the system to work over any length of time. For example, if the effects of gravitation field effects of the clocks (an effect we understand thanks to Einstein's theory of general relativity) are not corrected an error of about a nanosecond per second will accumulate and will render the GPS technology useless within a minute or so.

In this activity, the students will be asked to make estimates of these errors and compare with what they know about the accuracy of their watches. Information about atomic clocks and the role of our advanced theories such as general relativity in the GPS technology will be shared.

Activity 6: extension to plane and space

A simple extension to positioning on two-dimensional place can be done with three intersecting circles. Extensions to three-dimensional space can be visualized with intersecting spheres. This may require the use of ball, and cut spherical caps to visualize the intersection.

Some activity of describing a location on the map relative to reference points such as topographical features can orient the students to the importance of reference points. A desired outcome of this activity is to recognize how many such reference points are needed for a general positioning procedure.

Concepts, assessments, and questions for discussion

While continuous formative assessment is an integral part of the inquiry-base method of these lessons and activities, it is useful to identify the concepts and questions that these activities address. Targeted questions can then be formulated to assess the pre- and post-conceptions of the students.

Several concepts were discussed: reference points; measuring distances time keeping; speed of signals and relationship between distance and time; estimation and correction of errors.

Some assessment and discussion questions were discussed:

1. Where are you?
2. How does GPS/computer/your phone know where you are?
3. What are some ways you can locate your position?
4. How many pieces of information/sources do you need to locate yourself?
5. What precision is needed in order to locate our position?
6. Describe where an object is on a given map/in the class?