Gaining physical insight and independence in the modern physics lab

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Abstract

Imagine you are investigating new physics with tools that you have never used previously and you have to reproduce results achieved by many others. How would you proceed to acquire data? What would you learn from the process if you were given explicit, detailed directions? This is the dilemma faced by many students in the modern physics laboratory. Students only have their introductory laboratory experience to guide them through more difficult investigations involving much more complex physics.

Rather than having students perform a series of unrelated classic modern physics investigations, we developed an approach that involves sequential, conceptually focused investigations (a track of experiments). By taking this approach we are placing much greater emphasis on their understanding of physics, experimentation, and independence. The investigations typically start with an "introductory physics like" analog of the "modern physics" phenomena they are going to explore through out the semester. As the semester progresses, their experiments become more complex.

The traditional modern physics lab

- Students work individually (or in small groups) on classic experiments.
- The investigations are in no particular order.
- Student learning is gauged through lab reports.

Example Student Investigations

- X-ray diffraction
- Millikan Oil Drop Experiment
- Franck-Hertz Experiment
- Gamma Ray Spectroscopy
- Hall Effect
- Doppler Shift of Light

Problems with the traditional modern lab

- **The random order of conceptually and physically unrelated experiments with unrelated equipment leads to…**
  - …the students developing a minimalistic approach to laboratory – "tell me what I need to know, how to do it, and how to tell you about it". Knowledge learned in one lab is of no great use in following labs
  - …cook-book style procedures (to get students through the investigation and keep the equipment safe).
  - …difficulty gauging a student's conceptual understanding. If the instructor tells the student what to measure, how to measure it, and what graphs and analysis should be made, it is hard to gauge the student's learning. Does the student understand the reasons behind the experimental design, data collection, and analysis or has the student only learned how to follow the directions?
- **Since the experiments are classic, there is an overabundance of information which may or may not be accurate.**
  - Unless the instructor is very aggressive, students borrow information without necessarily understanding it. The internet is robust with good and bad information concerning these experiments.
  - Re-phrasing (parroting) material from multiple sources is not the same as understanding it.

Problems with the traditional modern lab (cont.)

- Students tend to concentrate more on the measured values rather than the data's meaning and an understanding of the overarching physics concept.
- Students wish to compare to accepted values as opposed to doing uncertainty analysis.
  - Students believe that any measurement within 5% of the accepted value is excellent no matter the accuracy and precision of the equipment.

How we approached the Problem

- Rather than have a series of independent, unrelated experiments that each student completes, we chose to have "tracks."
- Tracks are a series of closely related investigations. Typically the investigations have a common conceptual core.
- The initial investigations are designed either to provide the students with a conceptual background to the investigation through a simple mechanical analog or to provide insight in how a key piece of equipment operates.
- We provide the students with a series of guiding questions that they might be asked for a single investigation. They are provided with some background information, but there are **NO SPECIFIC DIRECTIONS** on what to do. We expect them to do design their own experiment and think.
- Rather than allow the students to hide behind a written report, we require poster sessions. The depth of a student's knowledge is obviously revealed in an interactive exchange.

The advantage of Tracking

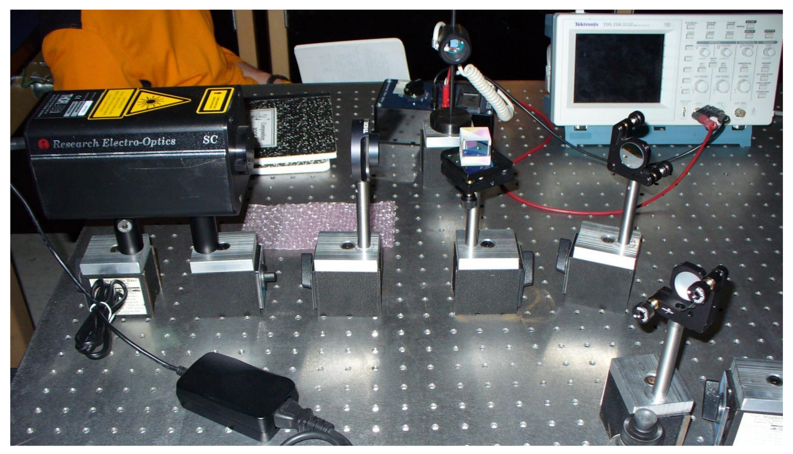
- Students gain expertise with a particular technique and set of equipment
- The earliest experiments don't use expensive equipment which allows us to move away from cook-book write-ups without endangering the equipment.
- Knowledge from one experiment is useful in future investigations.
- Student acquire much greater knowledge of the equipment they used as well as
- Students will repeat an experiment if their initial performance is unsatisfactory.(no other person/group is waiting on the equipment)
- Students gain independence.

The disadvantage of Tracking

- Students are not personally exposed to a wide array of phenomenon and techniques except through discussion with other students

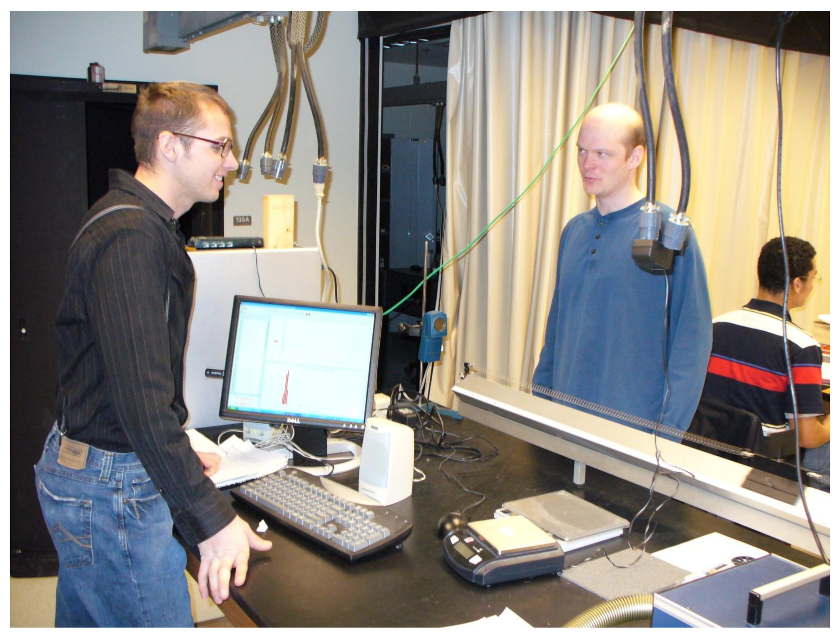
Some of the Tracks Developed

Laser Physics
Fabry-Perot
He-Ne Laser (aligning cavity)
Nitrogen pumped dye laser
Spectroscopy of Iodine molecules



Spectrometers and analysis
Spectrometer
Construction of a spectrograph
1/2m monochromator
Cs Dimer spectroscopy

Gamma Ray Spectroscopy and Nuclear Decays
Mechanical Analog of ½ life
Histograms of pulse heights
Gamma ray spectroscopy
Measurement of Cs ½ life



Fourier Analysis
Driven Oscillators
Michelson Interferometer
Doppler shift of light
Fourier Spectroscopy

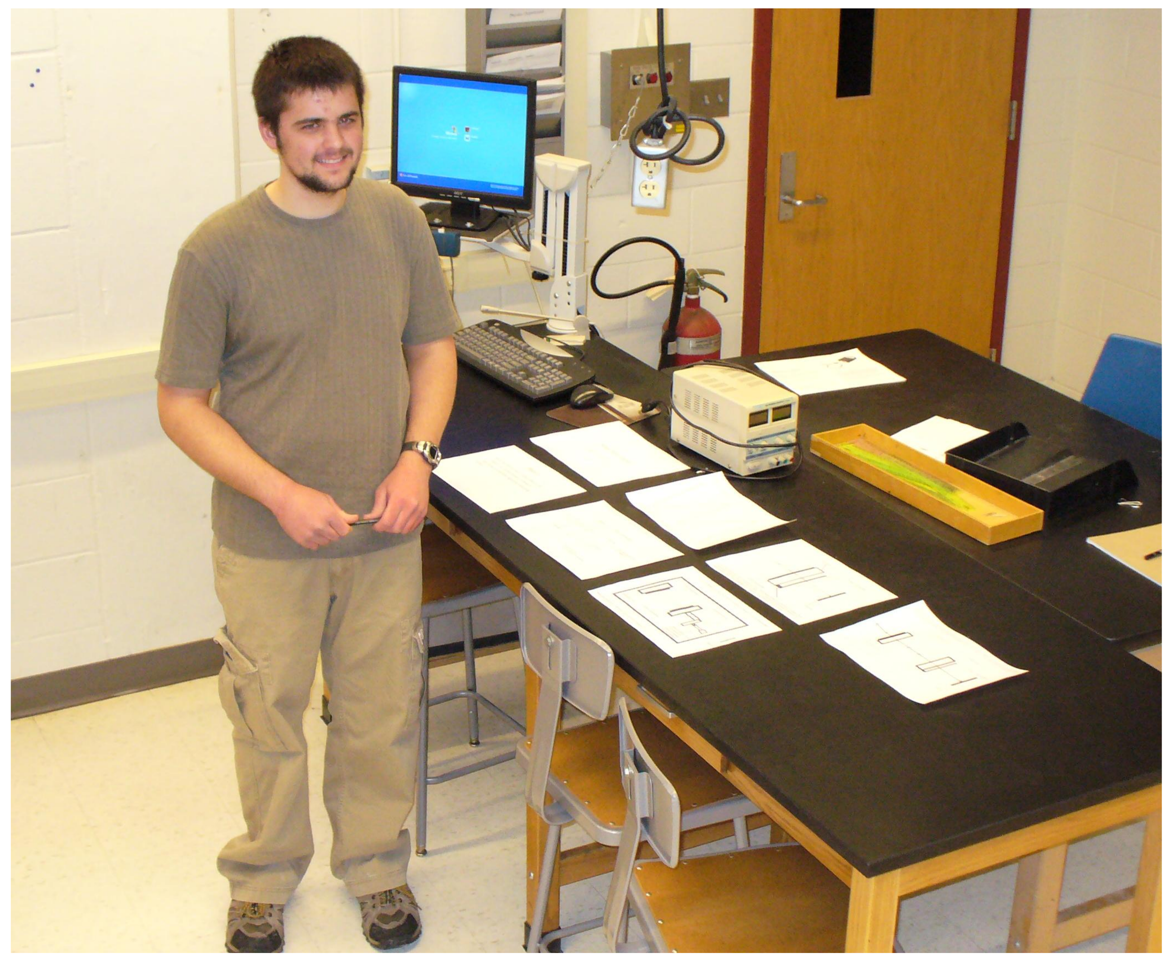
Example, The Gamma Ray Spectroscopy Track

- Histograms of pulse heights.
  - Pulses due to gamma rays are created using a scintillator, photomultiplier, and a gamma ray source.
  - An oscilloscope (set to single event trigger) interfaced with a computer, records several hundred pulses.
  - A histogram is made of the number of events vs. each pulse height.
- Introduction to the Multichannel Analyzer and Beer's Law.
  - The gamma ray pulses are now sent to a multichannel analyzer which performs the task of the oscilloscope and computer. Students perform gamma ray spectroscopy.
  - Multiple sheets of material (paper, lead, aluminum) are placed between the source and the detector. Students study how peaks in the histogram change as a function of material thickness.
- Mechanical equivalent of nuclear decay.
  - A plastic tray (with a small hole) is filled with ball bearings and vigorously shaken.
  - The time for a particular ball bearing to exit through the hole is random.
  - The number of ball bearings in the tray is exponentially related to time.
- Half life of Cs

Poster Sessions rather than Lab Reports

Posters serve four purposes:

1. Provide an assessment of how well each student understands his/her investigation and track.
2. Provide professors with insight into student misconceptions of the physics
3. Reveals "holes" in student understanding of introductory material.
4. Provides information about each track to the students doing other tracks.



- We found that the students ask very probing questions of other students physics work. They really try to understand what each other has done.
- As there is a quiz at the end of each open session, students are motivated to ask each other questions.

Our observations

- Poster sessions are an effective method for determining student understanding.
  - We can probe any (and every) aspect of the experiment.
  - We (professors) easily expose borrowed information that is not understood.
  - We feel that this method is a much better gauge than lab reports despite the use of laboratory time.
- Students, while initially resistant to the process, find it refreshing to have laboratories which are not solely following directions.