Student-built Lab Equipment via an Arduino and Modeling Instruction

Nathan Moore (nmoore@winona.edu) and Andrew Haugen @ Winona State University, PST1B14, Monday, 7/28 8:30-9:15pm

Abstract: What would the Introductory Physics class be like, if, at the start of the term, every student bought an ultrasonic motion detector at the bookstore along with the latest edition of Serway? We've experimented with this idea by having our students purchase an Arduino-based "labkit" containing a microcontroller and a variety of cheap sensors. In two separate semesters we've had students create and deploy data acquisition systems with varying degrees of success. Given that many students don't arrive at the University with knowledge of programming, we've found that Modeling Instruction may provide a suitable intellectual framework for the inclusion of DIY lab apparatus. Briefly, students create models for how the sensors behave and report measurements, and then the students deploy these models to solve context-rich problems.

In University Physics 1: What's the strength of Linguini?

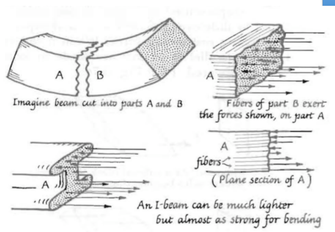


Fig. 5-5. Bent Beam. Stretching and compressing oppose bending.

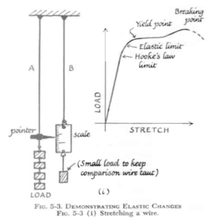


Fig. 5-3. Demonstrating Elastic Changes. Fig. 5-3 (i) Stretching a wire.

Physics for the Inquiring Mind, Eric Rogers

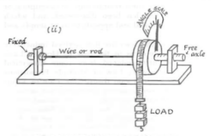


Fig. 5-3 (ii) Twisting a metal rod or wire. The left-hand end of the specimen is clamped and cannot turn. The right-hand end is attached to the large wheel which is free to turn. Loads are hung on a tape which is wrapped around the wheel's circumference. A pointer on the wheel shows the angle of twist.

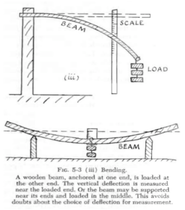
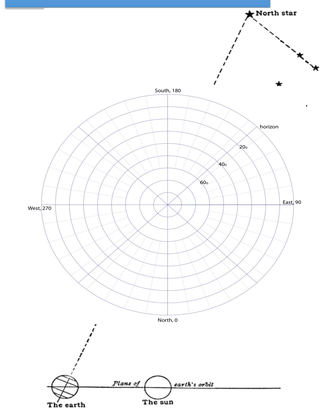
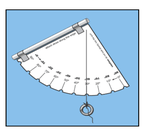


Fig. 5-3 (iii) Bending. A wooden beam, anchored at one end, is loaded at the other end. The vertical deflection is measured near the loaded end. Or the beam may be supported near its ends and loaded in the middle. This avoids doubts about the choice of deflection for measurement.

In College Physics 1: What's the rotational speed of the Big Dipper?





http://cse.ssl.berkeley.edu/AtHomeAstronomy/activity_07.html

What would it be like if every student had their own motion detector in their dorm room? What would they do?

See the editor of Make on Colbert,
http://www.colbertnation.com/
the-colbert-report-videos/311944/june-08-2010/mark-frauenfelder

"Makerspace in the Clasroom"
http://makezine.com/2014/01/10/makerspace-in-the-classroom/

But a motion detector isn't enough! I want:

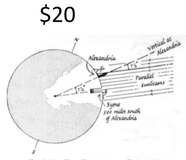

Ultrasonic Distance $30


Gas (ethanol, CO, etc)

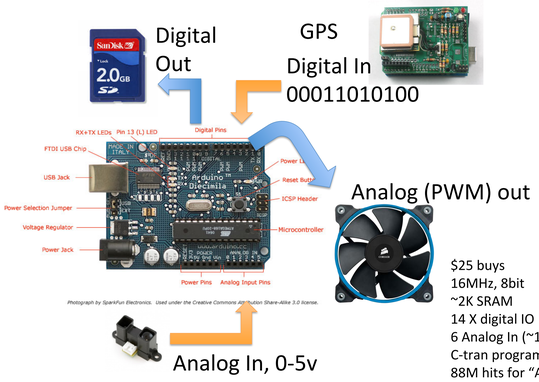

IR Distance


3-Axis Accelerometer $20


GPS Shield + Antenna ($50)



An Arduino (microcontroller) facilitates (DIY) Data collection & control



$25 buys
16MHz, 8bit
~2K SRAM
14 X digital IO
6 Analog In (~10bit ADC)
C-tran programming
88M hits for "Arduino Programming"

How do you program a dishwasher?

(That's what the micro inside an Arduino is used for…)

~~Assembly~~
"Arduino" language
(subset of C/C++)

Avoid:
fancy function calls,
Floating point math,
Pointers, C++ etc

2000 bytes of working memory means:
500 long ints
or
1000 ints (0-64k)
or
500 floats
or
2000 characters

Or, how do you program a Steelmill?

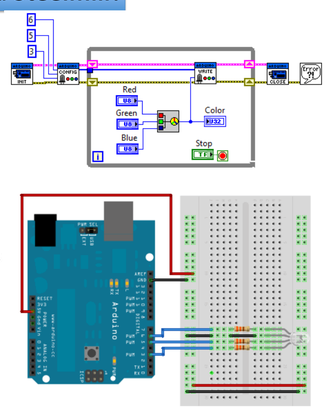
National Instruments Labview (programming "by cartoon") can use an Arduino as cheap physical interface.

Labview is widely used in Engineering Test Industry, DSP

Students can take a NI certification test

Arduino+Student Edition for ~$50

https://www.sparkfun.com/products/11225



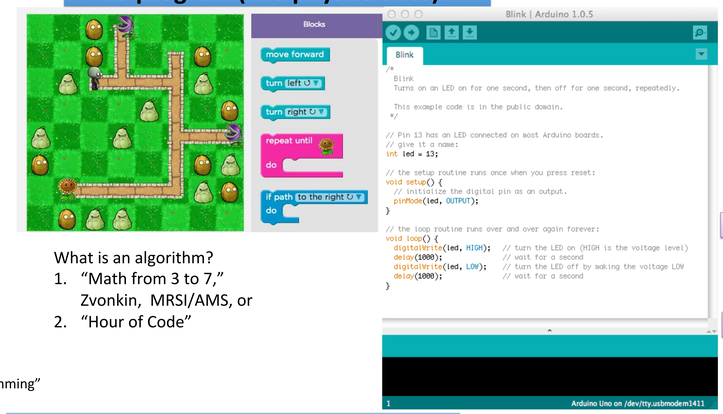
What did we try?

Two sections of University Physics 1 had a revised lab for which they purchased an ~$60 Labkit, consisting of an Arduino + sensors. Over the semester students learned how to program, interface with sensors, and deployed their data acquisition systems to complete "standard" University Physics labs. Spring 2011 students used the Arduino programmer and Spring 2013 students used Labview for interfacing. Lab times became open-ended workshops.

Anecdotally, students love to solder, some engineering majors used Arduinos in their senior design projects, other students took NI's certification exam to improve their resumes, and one student learned the topic well enough to be offered an internship at SpaceX.

An unusual approach creates friction however, and instructors must continually "sell" the idea that a novel educational approach has value outside of just learning the physics.

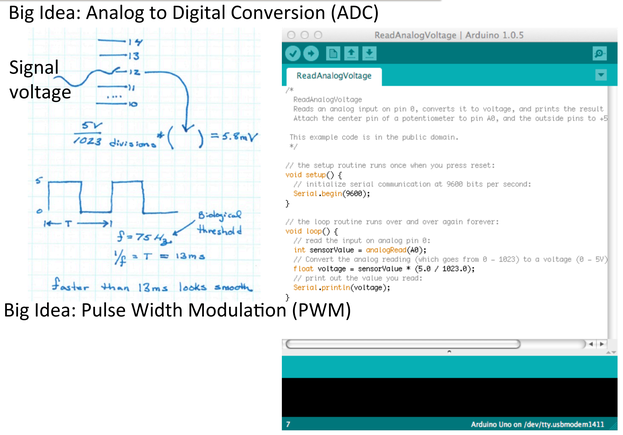
How do you teach a (physics) student to program (in a physics class)?



What is an algorithm?
1. "Math from 3 to 7," Zvonkin, MRSI/AMS, or
2. "Hour of Code"

How do you teach a (physics) student to interface a microcontroller (in a physics lab)?

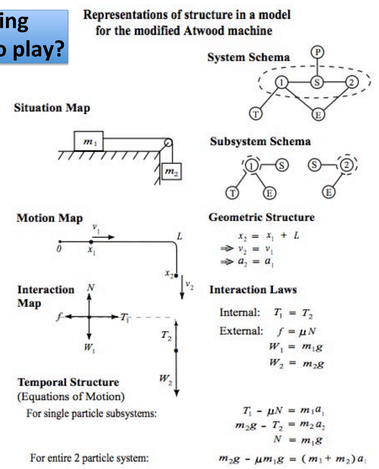
Big Idea: Analog to Digital Conversion (ADC)



Big Idea: Pulse Width Modulation (PWM)

How does Modeling Instruction come into play?

- 3wk workshops @ ASU
- Physics (Physical Science, Mechanics, E&M), Chemistry, Biology
- Incredibly high FCI gains, PISA scores, student maturity
- Students are "prepared for college"
- True Vygotskian social construction



Model Development
↓
Model Deployment

For more, see:
http://modelinginstruction.org/
http://youtu.be/3GkY-ZXnx4w
http://modeling.asu.edu/modeling/mod_cycle.html
http://modeling.asu.edu/R&E/ModelingMeth-jul98.pdf

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An Example Activity: Let's build a GPS speedometer

Model Development
1. Context-rich Concrete preparation
2. Sensor Data Collection
3. Mathematical Model-Building
4. Algorithmic Model-Building

Model Deployment
5. (Engineering) Applications

Context-rich Concrete Preparation:

Traditional speedometers are based on wheel circumference. If tires are not factory standard (eg low air, worn tires, irregular road surface, etc), we can't trust the reading. Let's build a speedometer that uses GPS. Design constants are…

Sensor Data Collection:

- How do we get GPS sentence out of the antenna?
- How and where do we need to hold the antenna?
- What wiring connections do we need to supply?

Mathematical Model Building:

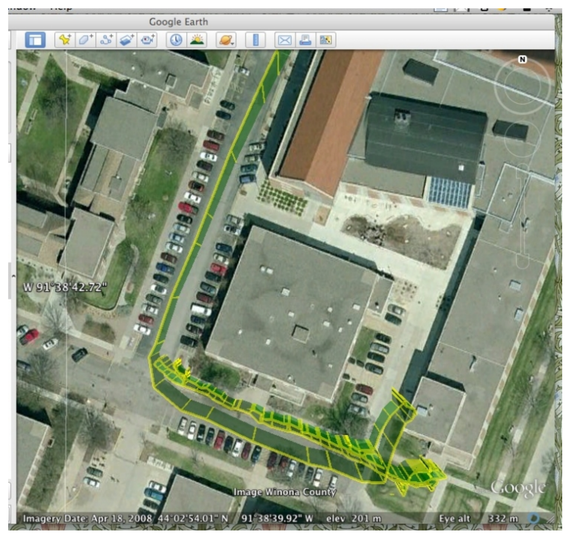
- How can we turn lat-long into "normal" position?
- How can we get velocity from position?

Algorithmic Model Building:

- Code up the above math model.
- How often should we measure GPS?
- When/How should the data be reported?
- Should Errors be mentioned, triggered, etc?

(Engineering) Applications:

- How can we use multiple (10) position measurements to get a more accurate velocity?
- If we also had data on engine fuel consumption, please compute instantaneous MPG or determine the most efficient speed.
- GPS sentence also contains velocity, how does our measurement compare to the stated value?
- If two cars communicate their GPS data, how could you use this to increase vehicle safety (this is a new US DOT standard…)



Here's an example data collection. It was rainy on 16 November, so I called my wife for a ride home. In the image below, you can see me walking back and forth for a little while before she came, and then me driving away. A Google Earth .kml is essentially an ASCII file containing a list of (lat, lon, altitude) – easy to write out with an Arduino.

Thanks to Scot Stroh, Tia Troy, Megan Reiner, Tucker Besel, and Spring 2011, 2013 sections of Physics 221 at Winona State University.