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TEACHING PHYSICS CORE IDEAS TO CONTENT GENERALISTS

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Synopsis:

We describe the physics content course for future elementary teachers at Iowa State University and our textbook for this course, "Children Doing Physics: How to Foster the Natural Scientific Instincts in Children." The course consists mainly of teachers performing the same experiments their future elementary students will be doing: measuring masses and length, making clocks to measure time, making electroscopes to measure charge, building a solar powered car, etc.

Teaching Physics Core Ideas to Content Generalists

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Abstract

We introduce instructional material designed to fit a physics content course for first year undergraduate students in elementary education programs.

The instructional material specifically is the textbook[1] titled "Children Doing Physics: How to Foster the Natural Scientific Instincts in Children." The course consists mainly of teachers performing the same experiments their future elementary students will be doing: measuring masses and length, making clocks to measure time, making electroscopes to measure charge, building a solar powered car, etc.

When a child builds something and makes it work, there is a sense of pride and ownership that is familiar to all scientists, and which is often the main motivator for a life in science.

The course consists mainly of future teachers doing what scientists do: building instruments and making measurements, plotting data and understanding nature and how it works. These future teachers become skilled at performing these experiments and making these measurements such that, in future years, they will have a collection of interesting experiments in their classrooms.

1 Needs and conceptual framework

Teacher candidates in the Elementary Education program and/or Early Childhood Education program are, for the most part, "content generalists" in terms of science. According to the current literature, teacher candidates who are to be science content generalists most often enter the program with formal preparation from only two or three specific courses they have taken in life sciences and physical sciences during secondary school. Therefore, it is likely they lack sufficient subject matter background and depth. They may have indifferent or even negative attitudes toward science and science teaching and, as a result, may lack sufficient confidence in science teaching. Moreover, teacher candidates are often inadequately grounded in the fundamentals of inquiry-based science teaching processes that promote the use of evidence, logic, creativity, reasoning, thinking, and communication skills, as shown in Fig. 1, (Newman, Abell, Hubbard, McDonald, Otaala, & Martini, 2004).

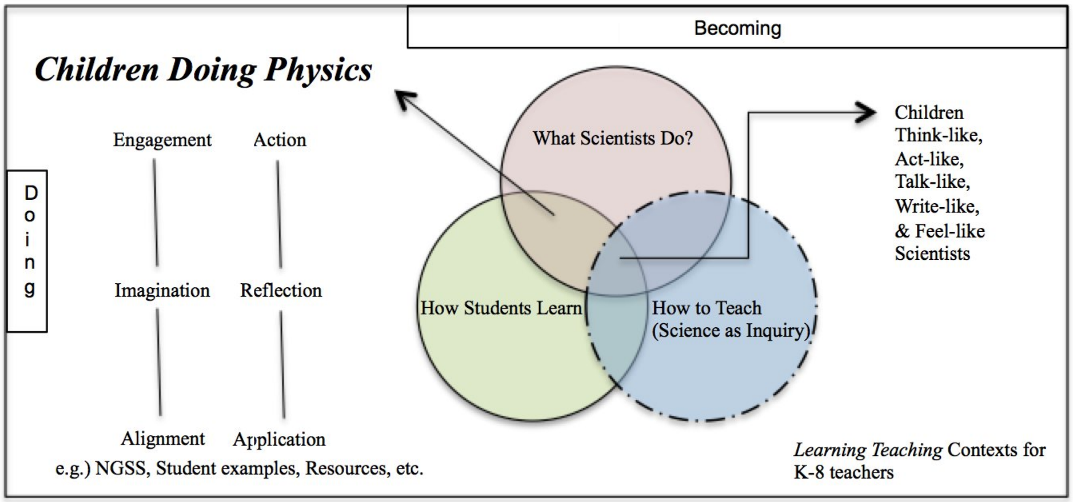

Figure 1: Conceptual framework.

Children Doing Physics is our guidance for the journey of teacher candidates to become authentic teachers while they are practicing the actual *doing of science*. The big picture behind this book-which will help you understand the primary concepts and goals of this book and how they come together as a whole-is illustrated in figure 1. *Children Doing Physics* fits within the K-8 teaching context and has three rings of inspiration.

The point where the three rings converge is the root from which the all encompassing purpose of *Children Doing Physics* grows: children will think-like, act-like, talk-like, write-like, and feel-like scientists. The parameters that lie between the ring of "*What scientists do*" and the ring of "*How students learn*" have been designed in a way that will guide teacher candidates through their active participation in the following fundamental exercises: 1) Articulating scientific big ideas, 2) Drawing and otherwise illustrating ideas, 3) Exploring theories and experiments, 4) Inquiring collectively, 5) Inventing devices using core scientific principles of physics, 6) Making working models, 7) Practicing rules and procedures common to all scientific realms, especially units, 8) Reflecting upon each activity, 9) Journaling, in science notebooks, 10) Tinkering with tools that scientists use, and finally 11) Tracing and sharing science stories and history.

It should be clear from the outset that the third ring "*How to teach (science as inquiry)*," is not the main purpose of the course. Rather, we consider this ring as one of the essential elements in the big picture of *Children Doing Physics*. The parameters of this ring are designed to help teachers develop a logical starting point for discussing the pedagogical aspects of activities for children in terms of the importance of each scientific idea. These will include: Science, Technology, Engineering, and Mathematics (S.T.E.M.) connections (The "Whys"), possible pedagogical approaches (The "Hows"), and alignment with the Next Generation Science Standards (The "Whats" in NGSS). The third ring is *porous*. This means that we encourage our teacher candidates to be open about individual aspects of their approaches to learning teaching. In essences, we see their science teaching as always in a "beta" state, constantly upgrading on an ongoing basis.

2 Purpose and philosophy of teaching children

Benjamin Franklin was an excellent scientist as well as a publisher, Founding Father, and statesman. He also understood learning, as evidenced in this quote

> *"Tell me and I forget. Teach me and I may remember. Involve me and I learn."*
>
> - Benjamin Franklin, 1751

This course and its corresponding book is a guide for elementary school teachers for teaching basic physics to schoolchildren, roughly from kindergarten through eighth grade. It is a collection of hands-on do-it-yourself experiments that children can do in an ordinary classroom with items generally available at hardware stores, grocery stores, home improvement centers, and from the Internet.

The basic idea is that children are natural scientists and, like all good scientists, they like to play, to try new things, to make things, to see if they work, and then to try something else. That is the point of this book:

> to bring future elementary teachers into a university teaching laboratory environment and let them play with physics toys, make clocks and bridges, measure light from atoms, build and use solar panels to run a motor, make waves, measure the thermal expansion of metals, build a musical instrument, make a simple motor from a battery and magnet, work with a basic computer, repeat Galileo's experiments on motion, etc.

All good physicists started young making, doing, building, and playing with toys, tools, and gadgets.

This expresses the essential goal of this book: bring children to build something with their own hands, even with their own ideas, and having built something they will achieve what a psychologist calls "ownership," that sense of accomplishment that physicists know is the key motivator for a life in science. One of Albert Einstein's many quotable quotes is "The pursuit of truth and beauty is a sphere of activity in which we are permitted to remain children all our lives."

This sense of psychological strength is just as important as development of content knowledge. This means that individual teachers can be creative in their use of this material when balancing the motivation of children and the essential big ideas in physics identified in the Next Generation Science Standards. Indeed, an interested child is far easier to teach and learns far more than the unmotivated and uninterested child.

A good YouTube video can do wonders in a classroom, relieving the teacher from the burden of getting the details right about some experiment.

3 How this book is organized

Children Doing Physics has a total of twenty-two chapters. Each chapter is organized in a relatively consistent order in that core ideas are discussed within sections of each chapter, followed by three color-coded sections: physics behind in magenta, NGSS in cyan, and suggested materials in blue. These chapters are arranged in a logical way such that each previous chapter functions as an essential introduction to the succeeding chapter. Before opening Chapter 1, we include a topic concept map to help the learning journey of teacher candidates, providing them with the "big map" of how each chapter is organically related to and/or cross-related to the whole. We have also included at the end of this book an appendix that depicts how each chapter is related to the NGSS. In this appendix, we added four core and twelve component ideas in physical sciences and corresponding performance expectations by lower (K-2), middle (3-5), and upper (6-8) grade levels. Although we rearranged, to some degree, these ideas, they are all directed from NGSS (URL: nextgenscience.org, NGSS Lead States, 2013. NGSS related performance expectations in each chapter are also direct quotes from this source.

In each chapter, our methods of pictorial representation as mediating tools for our teacher candidates include the following: computer drawings, graphs, hand drawings, pictures, student artifacts, and so on. We intentionally included some pictures of natural classroom and lab settings. Furthermore, we recycled some of our own material intentionally to make the point that all kinds of "everyday materials" can be used for science activities. Any brand names showing in our pictures are purely incidental. We also added actual drawings so as to model the importance of having children to visualize and draw their own thought processes throughout the overriding scientific inquiry process that they are working through.

These chapters touch on almost all of physics, including short chapters on chemistry and biology. A brief table of contents is listed here. Each chapter contains sections on resources, suggested activities, a few quiz questions, physics explanations, connection to the NGSS, and materials.

1. Measuring mass (gravitational and inertia mass)
2. Measuring length (using various scales and some geometry)
3. Measuring time (building clocks and oscillators)
4. Measuring properties of atoms (diffraction gratings and atomic spectral lines)
5. Measuring properties of elementary particles (quarks and cloud chambers)
6. Measuring charge (static electricity and building electroscopes)
7. Measuring current: Solar Voltaic (assemble solar panels, build a solar car)
8. Measuring motion due to forces (Galileo's experiment, balls on inclined plane)
9. Measuring friction forces (friction and ways of measuring it)
10. Energy and work (work-energy theorem, braking, simple machines)
11. Braking an egg: the "egg drop" experiment (en engineering problem)
12. Statics: Building a bridge (building bridges, arches and domes)
13. Heat, thermal expansion, and insulation (expansion of metal, heat transfer)
14. Heat engines (build simple heat engines)
15. Measuring wave properties (build a wave machine, measure wave properties)
16. Making a musical instrument (applications of sound waves)

17. Light and optics (lenses, build telescope and microscope, color and art)
18. Magnets and Induction (measure magnetic fields and induced voltages)
19. Making an electric motor (force on current in magnetic field, build motors)
20. A Real Computer: Raspberry Pi (a $35 computer to use)
21. Chemistry (ionic and covalent bonding, burning methane)
22. Biology, life sciences, and physics (T. Rex walk? Cat's eyes, neuron voltage)
App. A. NGSS: Next Generation Science Standards
App. B. Iowa Core Physical Science Standards (K-5)
App. C. Des Moines schools physical science standards

3.1 Concept map

The concept map of physics core and subcomponent ideas as used in the instructional material, and shown in Fig. 2.

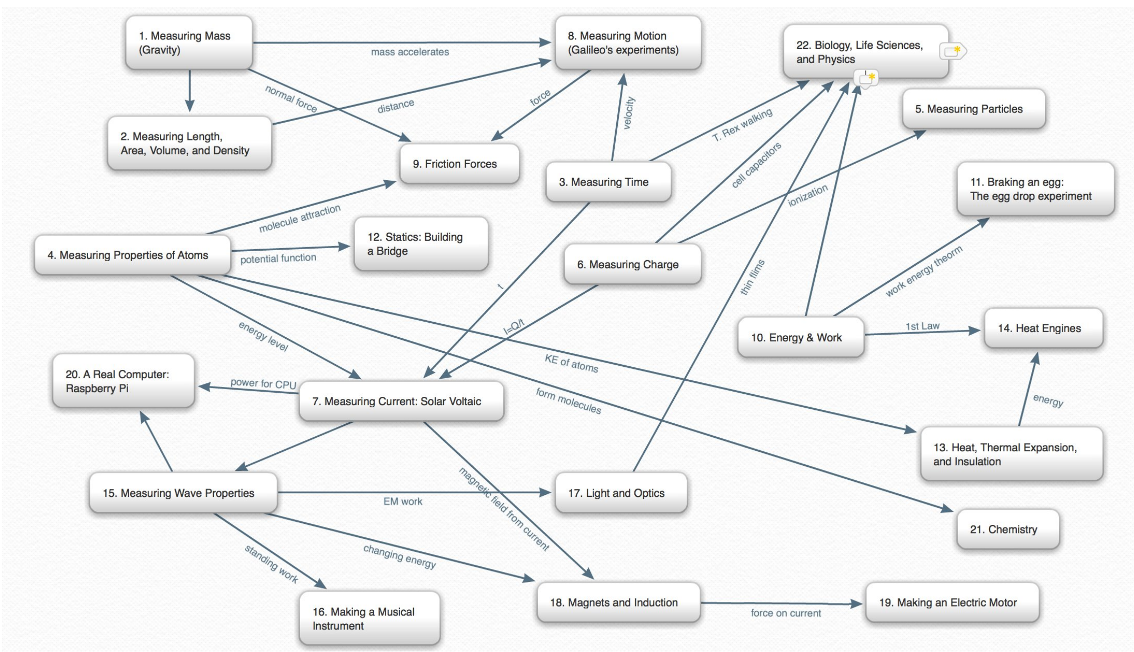

Figure 2: Concept Map.

4 Teaching and learning with everyday materials

The course as presently taught is one lecture early in the week, followed by two two-hour laboratory sections at bare tables similar to those in an elementary classroom. After an introduction to the week's activities, the laboratory sessions are taught by teaching assistants (both physics graduate students and undergraduate physics majors).

All materials are inexpensive, mostly bought locally from grocery stores and home improvement stores, while some items are easily and inexpensively bought from the web.

Mostly, all of the building and measuring in the lab are done with simply made instruments, using duct tape and common materials. This enables these pre-service teachers and their future students to understand completely what it is they are doing. There are plenty of excellent physics instruments and experiments that can be bought, but these are effectively 'black boxes' to students.

Figure 3: The first figure of the text illustrating the "hands-on" style of the course.

Individual teaching assistants have their own styles of teaching and varying degrees of rapport with their laboratory classes.

5 Web resources

The Khan Academy[2] (`www.khanacademy.org`) is a treasure of simple 10-12 minute recordings of Salman Khan explaining math, physics, and chemistry, in addition to economics, art, and history.

The amount of good material on the web is extensive and impressive, from national professional societies, to personal and professional youtube videos, to do-it-yourself home videos.

If an elementary teacher is unsure what to do in science the next week, just google 'Bill Nye [any physics term]' and you will likely get an interesting video to start off a science discussion. (`www.sophia.org/billnye`)

1. The Institute of Physics (UK) has a vast resource of educational material on their website `www.iop.org/education/index.html`. A well-hidden link on this IoP site is for international education and the following link has ninety experiments, some very easy and clever, for teaching physics with minimal resources: `www.iop.org/about/international/development/resources/page_43501.html`

2. The Vega Project (`http://www.vega.org.uk/`) has a collection of videos, including interviews and lectures by famous scientists and experiments and instruments to build.

Several other useful websites about elementary education are

- `cse.ssl.berkeley.edu`
- `fi.edu/guide/hughes/energyconservation.html`
- `nobelprize.org/educational`
- `ocw.mit.edu/courses/physics` - university physics lectures (MIT)

- petpset.iat.com/htm/pset2.htm
- physicsclassroom.com/class
- school.discoveryeducation.com
- school-for-champions.com/science
- sciencenetlinks.com
- web.mit.edu/jbelcher/www/anim.html
- wisegeek.com

The fourth website is the MIT OpenCourseWare physics lectures, consisting of fifty-minute regular university undergraduate physics lectures delivered in a lively way and interesting for the future elementary teacher who wants to understand physics deeper. The websites listed here are not exhaustive, and there is much more if you are patient to look.

People who understand nature and how it works are able to form a movie in their mind. Being able to just watch how a system develops, e.g., a pendulum, a mass on a spring, etc., is very valuable. One site developed by Walter Fendt has dozens of applets showing simulations of many things in physics:

walter-fendt.de/ph14e/index.html

Teaching techniques, support information, and science standards and content are available at the following sites:

educateiowa.gov/pk-12/iowa-core/iowa-core-science (Iowa Core Science content)

nextgenscience.org/next-generation-science-standards (Next Generation Science Standards)

nsta.org/preservice/ (Professional development)

tools4teachingscience.org/ (Teaching techniques)

Small equipment and parts are available at the following sites: amazon.com (Good for many items for this course; probably the

best go-to site.)

digikey.com (All you need in electronics.)

scientificsonline.com (All optics.)

surplusshed.com (Some optics and some mechanics; surplus.)

This course has been relatively well received by students[3], with the usual proviso that most students do not like physics. These students take a more formal course in science methods in their fourth year in the School of Education.

References

[1] *Children Doing Physics: How to Foster the Natural Scientific Instincts in Children*, John Hauptman and EunJin Bahng, Cognella Academic Publishing, First Edition, 2016.

[2] The Khan Academy, khanacademy.org, is a collection of invaluable 10-12 minute discussions of topics in physics, chemistry, mathematics, history and art, computing and economics. It is a go-to website for a free and easy lecture on many science topics for students, teachers and parents.

[3] An interview of the authors and comments from a student: https://www.hs.iastate.edu/news/2015/09/21/children-doing-physics/