An Integrated Earth Science, Astronomy, and Physics Course for Elementary Education Majors

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ABSTRACT

Physical World is a one-semester course designed for elementary education majors, that integrates earth science, astronomy, and physics. The course is part of a four-course set that explores science concepts, processes, and skills, along with the nature of scientific practice, that are included in state and national standards for elementary school science. Geoscience concepts, such as water and seismic waves, are used to illustrate general principles of physics, such as wave transmission, refraction, reflection, and interference. Laboratories are drawn from both introductory physics and earth science courses and have been redesigned to have a strong inquiry component. Pre-assessments were used to evaluate students' prior knowledge of key ideas. The use of pyramid tests measurably enhanced student performance. A major theme of the course is how science is represented (and misrepresented) in the media. Pedagogical challenges encountered in the course are due to various factors, two main ones being lack of previous experience with the natural world among a largely urban student body and the diversity of material that the course covers.

INTRODUCTION

The first formal exposure to science that children have is in their elementary school classrooms. Current state standards often require that elementary school teachers be knowledgeable of a broad spectrum of scientific topics so that they can help their students learn. For example, Illinois State Learning Goal 12 states that students should "understand the fundamental concepts, principles and interconnections of the life, physical and earth/space sciences." For elementary grades, these include concepts as diverse as motion, energy, force, weather, earthquakes, the order of the planets, and the phases of moon, as well as the basics of ecology.

For most pre-service elementary school teachers, the need to become familiar with this diversity of subjects is not met by taking a subset of courses offered in the scientific disciplines. A student taking two semesters of biology to meet a science distribution requirement will be unfamiliar with the basics of astronomy or chemistry.

An unbalanced exposure to the range of scientific topics may well contribute to the belief among elementary teachers, as identified by the 2000 National Survey of Science and Mathematics Education (Smith, et al. 2002) that they are less qualified to teach science than any of the other subjects for which they are responsible. Keagan (2006) attributed that to a generally accepted claim that "Often, educators at the elementary level never liked science in the first place," and quoted former Merck CEO P. Roy Vagelos, "'Teachers are so frightened of these subjects that they transmit the fear to the children. These kids are afraid of science.'" (p. 27).

In order to strengthen prospective elementary school teachers' knowledge of and attitude towards science (its concepts, processes, nature, practice, history, value, and impact), a group of science and education faculty at the University of Illinois at Chicago (UIC) and Chicago-area community colleges developed a set of new science courses for elementary-education majors (Varelas, et al. 2008). The goal of these courses is to help prospective elementary school teachers become qualified for and comfortable in teaching science in their classrooms, having experienced learning science in ways useful for their future careers. The development of these courses was enhanced by conversations with faculty at the University of Michigan at Dearborn, who have also designed and implemented science courses for elementary education majors (Luera and Otto 2005).

The course set consists of three four-credit hour lecture and lab courses, known as the "World" courses, and a one-credit hour capstone project course. The three World courses are the *Physical World*, the *Chemical World*, and the *Biological World*. The cross-disciplinary nature of these courses is intentional and explicit; each incorporates and integrates concepts drawn from earth and space science, environmental science, biology, chemistry, and physics. For example, the Physical World is not a traditional physics course, but one that illustrates physics concepts using earth science, biology, and astronomy; in other words, it both uses the world to illustrate physics and looks at the world from a physics perspective. The use of the word "World" thus has multiple purposes. In addition, it indicates the relevancy of science to understanding the world around us, and signifies that earth science concepts are explored in all three courses. For example, fossils are discussed in the Biological World and minerals and global warming in the Chemical World.

The fourth course, the *Project-Based Seminar in the Natural Sciences*, serves as a capstone course, taken after all World courses or concurrently with the last one a student is taking. There, students synthesize knowledge gained in the "World" courses by designing, conducting, and presenting their own research study that involves data collection and analysis. Recent versions of this course have involved the students in web-based group projects on the urban environment in the vicinity of the campus.

It should be emphasized that these classes are not intended to be teaching methods courses. They are, instead, college-level introductions to the content areas of

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Content: Media. These criteria do not focus on the science itself, but on how the media present the topic. For example: In what manner do they present science and scientists? Are they making concepts up for dramatic effect or have they really done their homework? What kind of language/images are they using to describe the scientific ideas? Does there seem to be a political agenda? Etc.

Points	**Criteria**
0	No discussion of how scientific topic is presented in the media
1	Unclear or inadequate discussion of how the scientific topic is presented in the media; inappropriate examples given; major flaws in reasoning or explanation
2	Adequate discussion of how the scientific topic is presented in the media, but discussion is sketchy and/or limited examples given; decent reasoning and explanations
3	Full discussion of how the scientific topic is presented in the media, with specific examples given and described; reasoning and explanation clear and well thought-out
4	Outstanding discussion of how the scientific topic is presented in the media, with many specific examples given and fully described; reasoning and explanations clear, creative, and original

Content: Science. These criteria focus on the science itself. What is the current scientific thinking, including controversies, on this topic? Where and why is the media presentation accurate or inaccurate? Etc.

Points	**Criteria**
0	Missing or highly inaccurate discussion of the science
1	Poor job discussing science; missing supporting information (data, figures, examples, etc.); major flaws in reasoning or explanations
2	Decent job describing the science, but too general, cursory, or incomplete **or** with some inaccuracies or flaws in reasoning; lacking adequate supporting information
3	Satisfactory job describing the science, with some use of supporting information; adequate analyses and explanations
4	Good solid job describing the science, with excellent supporting information (data, figures, examples, etc.); analyses and explanations show clear understanding of concepts but are not necessarily creative or original
5	Outstanding discussion of the science, with superior supporting information (data, figures, examples, etc.); creative and original analyses and thoughts

References: Please use a standard reference format. References should be in both the body of the text and in a separate bibliography. Again, no more than three web pages and not only the web!

Points	**Criteria**
0	No references and/or not cited
1	Few references or all from web; missing or incorrect citations
2	Minimal number of references; properly cited
3	Numerous references; properly cited

Writing: All material should be in your own words! The wise revise.

Points	**Criteria**
0	**Plagiarized (also zero on rest of assignment)**
1	Disorganized; poor grammar, poor spelling; clearly not proofread
2	Decent organization; minimal number of spelling or grammatical errors; reads like a first draft
3	Excellent organization and grammar, no spelling or grammatical errors; clearly proofread and revised

FIGURE 1. Grading rubric used for term paper. Derived from an example supplied by Barbara J. Tewksbury.

science that students are expected to know to meet state standards as elementary school teachers. They differ from other introductory science courses at UIC by emphasizing the unity of, and relationships among, the many disciplines of science. They are also far more inquiry-based than the traditional courses, and instructors of these courses model engaging and meaningful teaching that elementary school teachers are expected to practice.

The development of all the new science content courses for elementary education majors, which are formally known as the *Integrated Science Content Courses (ISCC)*, was funded by a 3-year grant from the National Science Foundation, which ended in 2006. The courses were first taught at UIC in 2004. Each World course is on average taught two or three times in a three-year period, with the capstone course being taught every semester.

In this paper, we describe the structure of the Physical World course. The other ISCC courses are discussed in Varelas et al. (2008). The detailed development of the Physical World occurred when the first author attended the 2004 *Cutting Edge* workshop on *Designing Effective and Innovative Courses in the Geosciences* (http://serc.carleton.edu/NAGTWorkshops/coursedesign04/index.html). Many of the features of the course reflect concepts and ideas, such as rubrics and pyramid tests, learned during this workshop.

In this paper we put forth details about the Physical World course, identifying successes and challenges experienced by students who have taken the course and one of the instructors who have taught it. Our goal is to raise issues worth considering when planning science courses for elementary education majors, rather than to evaluate the extent of the success of this particular course.

Student Body

The course enrollment consists of 42-48 elementary education majors, although the course is open to other non-science majors if space is available. Demographically, the class is overwhelmingly female, with typically no more than three male students. The class is ethnically and racially diverse, reflecting the urban setting from which UIC draws its student body, and most students commute to campus. Moreover, most students lack direct experience with the natural world.

COURSE FEATURES

Course Goals and Tools Used to Reach Them

The overarching goals for this course are that students become able to apply basic physical principals to:

1. Develop explanations for observations about everyday natural and human phenomena;
2. Make predictions about phenomena that are not directly observable; and
3. Assess scientific ideas encountered in the media.

Goal 1 is addressed by using case studies and examples drawn from geological and astronomical phenomena, as well as, technological examples. For instance, the principles of mechanics are illustrated using landslides. Following a presentation of the Gros Ventre landslide as a case study, topics such as velocity, acceleration, force, stress, and strain are discussed in the context of landslide causes and motions. Similarly, electrostatics is introduced through a discussion of the hazards posed by lightning (text files of these lectures are available by request from the first author).

Goal 2 focuses on the underlying concepts of fact, theory, and hypothesis in science. For example, students are introduced to the idea that the core of the Earth is a theory, since it has never been directly observed. Throughout the course of the semester, they study evidence from geomagnetism, seismology, and heat flow that are compatible with the existence of the core. Using their knowledge of wave types and their propagation, they can predict that the Earth has a liquid outer core. They are asked to envisage what the behavior of the magnetic field would be if the Earth had a giant permanent magnet in its interior and to see if this evidence is compatible with secular variation and reversals of the field. After being introduced to the concepts of longitudinal and transverse waves and their transmission, students are shown the S-wave shadow zone and asked to think about why this is consistent with a liquid outer core.

Finally, Goal 3 is addressed in the term paper, in which students chose a topic within science (not necessarily physical science) and determine how accurately this topic is covered in the media. Media in this case is broadly defined to include movies, websites, and television programs. The project is modeled during the first week of the semester, during which students watch a five-minute sequence from the film *The Core*. In this sequence, there is a rapid-fire presentation of "facts" about the core, the solar wind, and the Earth's magnetic field. The students are asked to choose three of these ideas and to determine whether they are scientifically valid.

Students have chosen a wide variety of topics for their term papers, although there are some clear favorites. The films *The Day after Tomorrow* and *An Inconvenient Truth* inspired a number of papers on global change, whereas movies such as *Jurassic Park* raised interest in cloning. Other popular topics include tornadoes (*Twister*) and the Bermuda Triangle. The paper is graded based on a rubric supplied to the students at the beginning of the semester and shown in Figure 1.

Integrating Earth Science, Astronomy, Physics, and Biology

The integration of multiple traditional science disciplines is an important signature of the Physical World course and is manifested in both the "driving questions" and the corresponding topics that define the units explored in the course. The major topics are:

Unit I. How do we "know?" The unit introduces aspects of the philosophy and sociology of science, such as, the concept of a scientific theory. The idea of a scientific model is discussed by considering the general circulation of the Earth's atmosphere. The history of plate tectonics is used to illustrate the concept of scientific revolutions.

Unit II. How do things move? The unit is the longest, taking about seven to eight weeks. Mass movements on the earth's surface are used to illustrate force, mass, and gravity. The discussion of gravity then leads into Kepler's laws of planetary motion and the causes of tides. The causes of seasons are briefly reviewed. Electricity and magnetism are described in the context of electric motors, lightning, and the Earth's magnetic field. Electrical currents provide the introduction into the flow of water in streams and blood in the human body. Heat and energy are explored in relation to climate and the earth's interior heat. The unit concludes with a discussion of entropy, evolution, and the "heat death of the universe."

Unit III. How do we sense the universe? The unit examines waves of many kinds, and how they convey energy and information. The 2004 Indian Ocean tsunami is used to introduce water waves and their motions. This provides the background for the physics of sound waves that is eventually related to the biology of the human ear. This topic is followed, in turn, by a review of seismic waves and what they reveal about the Earth's interior. Next comes the physics of light that includes a discussion of vision and the eye as an organ. A brief review of spectroscopy focuses on how it reveals the composition of the sun and stars. This provides necessary background for the final two units.

Unit IV. How far, how big? The unit focuses on the scale of the Earth and the universe, as well as the objects in it. Starting with the size of the Earth, students learn how the distances and size of the moon, sun, planets, and other objects in the universe are determined.

Unit V. How old are things? The final unit examines the history (and future) of the Earth and the Universe. Techniques of relative dating are briefly explored. Radioactivity is discussed in the context of radiometric dating, leading to estimates of the age of the Earth and solar system. This in turn leads to addressing fusion, and the history and future of the Sun and other stars. The course concludes with a discussion of ideas concerning the age and origin of the universe.

Laboratories

The laboratory experiences also reflect the cross-disciplinary nature of the course. Half of the laboratories were drawn from those already in use in introductory Earth and Environmental Science (EaES) courses. These include labs on waves, the Earth's heat budget, paleogeography, stream flow, radioactive decay, and size and mass of the Earth. These labs already possessed a considerable hands-on and inquiry component.

For example, the heat budget lab (Plotnick, 2005) integrates concepts of heat and light, seasons and eccentricity of the Earth's orbit, pole-to-equator temperature gradient, the albedo, and differences in heat capacity between continents and oceans. Students are provided with solar cells, which are attached to an ammeter and a light source. The solar cells are mounted on a device that allows their distance and angle relative to the light source to be altered. Students predict how light intensity changes as a function of distance and then compare their prediction to experimental findings. This laboratory allows them to discover the inverse-square law. They then compare the effect of changing distance, based on the Earth's aphelion and perihelion values, with the effect of changing solar angle during the seasonal cycle.

In the next part of the laboratory, students measure the relative amount of radiation reflected from black and white surfaces and predict how these surfaces will heat over time. Their prediction is then compared with measured temperature changes. In the final part of the laboratory, students determine the relative heat capacities of water and sand by tracking temperature changes under a heat lamp. They then explore the implications of these results for regional climates.

The remaining six laboratories were adopted from those in use by an introductory physics class, and were revised to reflect current inquiry-based standards for teaching science. The topics explored in these laboratories include forces, electricity and magnetism, optics, spectroscopy, sound, planetary orbits and the night sky. During the optics laboratory, students build a simple telescope that they keep. Similarly, they construct and keep the spectroscope that they use in the spectroscopy lab, to identify the gas present in fluorescent lights and to look for solar absorption lines. Both the telescope and the spectroscope are available from Project STAR (http://www.sciencefirst.com/), but the spectroscope is no longer manufactured. Parts of the telescope laboratory were adopted from one in use at Southern Illinois University (Lindell and Foster, 2004).

One of the challenges associated with teaching astronomical topics in an urban area is the heavy light pollution. In addition, most of the students live and work off-campus and find it difficult to return to campus at night. Thus, a Coronado SolarMax 60 solar telescope was purchased. This allows direct observations of the sun, including sunspots and prominences, in the H-alpha part of the spectrum.

Assessment

Given the diversity of students' prior knowledge and experience, it is important to perform pre-assessments in order to diagnose their level of understanding of the concepts and processes to be studied in a unit. Short one-page assessments containing a combination of a few multiple-choice and constructed-response items serve this diagnostic function. In these assessments, students receive credit for both wrong and right answers so that they are encouraged to answer the questions and reveal their thinking. It should be emphasized that the primary goal of performing these pre-assessments has been instructional, in order to guide the instructor, rather than focusing on research on student knowledge and learning.

The Astronomy Diagnostic Test (ADTv2.0), available at http://solar.physics.montana.edu/aae/adt/ (Hufnagle, et al., 2000) is a useful resource. Although

TABLE 1. PRE– AND POST-ASSESSMENT STUDENT PERFORMANCE IN TOPICS REPRESENTING PERFORMANCE IN THREE CLASSES.

Topics Assessed	% Students Correct, Pre	% Students Correct, Post
Cause of weightlessness in space	3.1	64.0
Qualitative understanding of law of gravity	38.5	39.5
Cause of seasons	51.9	77.9
Objects with different masses falling in vacuum	44.5	82.5
Speed of light other than in vacuum	35.7	54.4
Comparison of light and radio wave speeds	30.7	48.9
Definition of a light year	22.6	60.2
Age of the Earth (order of magnitudde)	39.0	65.2
Inverse square law of radiation	11.4	21.3

TABLE 2. COURSE FEATURES IDENTIFIED BY STUDENTS AS MOST OR LEAST HELPFUL OR ONES(S) STUDENT STRUGGLED WITH

Course Element	Most Helpful		Least Helpful		Struggled With	
	Frequency	%	Frequency	%	Frequency	%
Labs	26	46	10	20	2	4
Note-taking	8	14	16	32	11	21
Instruction/Instructor	14	26	6	12	0	0
Content	4	7	0	0	11	21
Tests/Assessments	2	4	3	6	23	44
Nothing	1	2	4	8	1	2
Other	1	2	2	4	4	8
Textbook	0	0	9	18	1	2

reliability and validity cannot be guaranteed when the entire test is not used, the authors do not object to administering only certain items as pre-assessments. Moreover, they encourage instructors to use the ADT as a posttest to assess teaching effectiveness on topics addressed in class and on ADT items. An example of an ADT item used in the Physical World course is:

Astronauts inside the International Space Station float around as it orbits Earth because:

A. There is no gravity in space
B. They are falling in the same way as the station
C. They are above the Earth's atmosphere
D. There is less gravity inside the station.

In three separate iterations of the course, 106 out of 131 students chose A and only 4 chose B during pre-assessment. Another question asked whether there would still be seasons if the Earth's orbit were perfectly circular. Over three classes, only about 50% answered yes. Thus, pre-assessments, which included some ADT items, clearly highlighted areas that needed particular attention which was, therefore, provided during the course.

Pooling data from three classes, Table 1 shows the relative success of the Physical World course in helping students understand certain topics for which pre-assessment data were collected. One obvious area of difficulty, even after multiple approaches to explaining it in both lab and lecture, is the inverse squared law as applied to either radiation or gravity.

Furthermore, to promote student supporting of each other's learning, all exams in the course are given using the cooperative or pyramid test structure (Yuretich, 2001; Zipp, 2007). Forty-five minutes are allocated to first taking the exam individually. The answer sheets are then collected but students retain the question sheets and a new set of answer sheets is handed out. Students then have 30 minutes to work on the exam together in small groups. Students' final scores reflect both their individual and group performance, with 80% of their final score coming from their score on their individual exam, and 20% from their score on their group exam.

The pyramid test structure has both qualitative and quantitative impacts on student learning. Students actively discuss and debate answers to questions, and teach each other. Furthermore, the average percentage of correct answers in the group administration rises 20% to 30% above that in the individual administration. An issue worth considering is what group composition best supports peer learning. Many times, if left to choose their groups, lower-performing students tend to navigate towards working with high-performing peers and passively accepting their answers as the group consensus. Random group assignment forces students to work with various peers and focus more on making meaning rather than on "fishing" for the "right" answer.

STUDENT REACTIONS TO THE COURSE

Practice and research show that students construct their experience in class in a variety of ways affected by a variety of factors (Bransford, et al. 1999; Donovan and Bransford 2005). These include the intended curriculum and instruction that the teacher enacts, and students' own experience, knowledge, beliefs, performance, and identity. These are considered to be a few of the many psychological, sociological, socio-cultural, and other dimensions that shape individuals' ways of relating to the content, people, artifacts, knowledge, and relationships that are encountered in a class. In the Physical World, we have assessed student response to the course using the Student Assessment of Learning Experience (SALE) survey. This instrument was originally developed at UIC to assess the student experience in courses taught by instructors who were participating in a professional development program. Nine open-ended questions ask students: whether the course met their expectations, why or why not; to identify the most helpful and least helpful aspect(s) of the course; to indicate the greatest struggle(s) they faced; and to think about and share some important ideas gained in the course that they could bring to K-12 classrooms. In two semesters, 46 students completed the survey and consented so that we could use these data for evaluation and research purposes. These students offered a variety of responses identifying several course elements as the most or least helpful for their learning in the course, and as the elements that they struggled with. Table 2 shows the frequencies and percents of the various features identified.

Students noticed various instructional tools used in the course (e.g., labs, pyramid test, notes, and group work) and noted that these facilitated their meaning and connection making. Out of the 56 course elements identified as most helpful, about half (46%) of them were the labs. Although about 40% of the answers that identified the labs as most helpful did not offer specific reasons, the rest provided cognitive (33%), affective (10%), and practicality (17%) reasons. Providing cognitive reasons, students noted: "the labs were helpful because they were very hands-on and helped me better understand the lecture;" "The labs were a great way to reinforce material covered in lectures;" "labs were good times of learning new material." Affective reasons included labs being fun, and practicality reasons showed a link between students' learning of science and prepararion for their teaching career ("[they were] kid-oriented learning labs"; "some of the labs we did seemed fun to teach in K-12 classes").

Although the course is a "content" and not a "methods" course, the students noticed the particular curricular, instructional, and assessment features and made connections with their own future teaching practices. They indicated that this course helped them become more prepared to "make certain aspects of the science and abstract ideas accessible to kids" and that they would adapt some labs they did during this course for their K-12 classrooms. Students also noticed the interdisciplinary nature of the course ("I like the fact that it included things that were learned in the other NATS classes") and the relevance to the science they will have to teach as elementary school teachers, but also the higher depth of the course curriculum ("material about the physical world generally learned in grade school was taught here. But it went beyond").

However, there were also struggles that students expressed in their comments. While some students were excited about "the new knowledge of the science of the world and how it works" and acclaimed that "science really can be fun," some others struggled with the content, note taking, and tests (21%, 21%, and 44% respectively of 53 responses given to the question about the element they most struggled with where some students noted more than one struggle). Students also noted that it was hard to study so many topics and concepts in such a short time ("My greatest struggle in this course was to keep up…too much material to cover in one semester"). Struggling with content and struggling with tests seemed to be related for some students, fused together with the high density of course ideas. The latter is a challenge that not only the students, but also the instructor identifies as such.

Furthermore, the textbook accounted for 18% of the student responses in the question about the least helpful element, yet another area that coincides with the instructor's own challenges. A student noted, "the textbook [is the least helpful] because we took extensive notes." Furthermore, note taking was an element that drew both positive and negative student reactions. Note taking was mostly associated with a least helpful element and a struggle. Although, some students found note taking useful to their understanding, they could not keep up with it and make sense of the ideas at the same time. This is indeed a complex tension in learning, namely balancing between understanding and making sense of ideas as instruction unfolds and, at the same time, keeping a rich record of ideas explored and discussed so that they can be revisited and made more sense of at a later time.

POSSIBILITIES AND CHALLENGES

The Physical World course is filled with opportunities for the students, but it also presents challenges that need to be considered by an instructor. As pointed out by the students, there is a great deal of content to be addressed in a single semester, as at the same time the course needs to have a pace conducive to inquiry-based science teaching and learning. Furthermore, the content needs to be addressed with the rigor of a college science course, as at the same time the course needs to also ensure a deep and meaningful understanding of the concepts and processes that the prospective elementary school teachers who take the course are expected to teach to their students. These demands necessitate a delicate balance that the instructor needs to achieve between depth and breadth of topics explored and, of course, experiences.

While teaching such a course, the instructor should also be mindful of the limited confidence in mathematics shown by many students. The course, in particular the laboratories, has a moderate mathematics component. For example, right triangles are used to determine the size of the Earth and the distance to the stars (parallax). Students also work with equations such as Ohm's Law and the relationships among force, work, and power. Although, course participants are expected to have high-school level competency in algebra, geometry, and trigonometry, many students struggle with a fundamental understanding in these areas. At UIC, this has been widely acknowledged as an issue that needs attention, and, therefore, elementary education majors are required to take two mathematics courses that focus on these competencies. Sequencing such courses appropriately relative to the Physical World course will contribute to lessening students' struggles with the mathematics aspects of the science course.

Among a largely urban raised student body, the instructor should not dismiss students' limited direct experience with the natural world. In the 2008 class at UIC, none of the students had even seen the Milky Way. Although, of course, there are plenty of resources that students may use to "experience" ideas for which they do not or cannot have first-hand knowledge, such resources are not equivalent to first-hand experiences (Louv 2008).

Choice of a textbook is also a major issue. Although a "physical science" textbook has been adopted at UIC (*Physical Science* by Bill W. Tillery), this text does not present an integrated, interdisciplinary approach to science that readily lends itself to use in this course. Students are told to use the textbook as an "encyclopedia" that will provide reinforcement and additional information on topics studied. However, a textbook that will closely map onto the course goals and syllabus may be more helpful in supporting and extending student learning in and out of the classroom.

Learning is greatly enhanced when students work on their term paper. However, in order to assess the quality of science presented in the media, it is necessary for students to consult reliable sources of scientific information. Although the Internet provides a plethora of sources, the potential inaccuracies and biases of some of them can be harmful to, rather than supportive of, student learning. Thus, taking measures towards making sure that the web does not become the almost exclusive source of information for students is very important. At UIC, in order to deal with this, students were given lists of sources of accurate information, including websites linked to professional societies and government agencies and names of journals such as *American Scientist*, *Nature*, and *Science*. They were also prohibited from using sites such as Wikipedia as sources of information and were limited to no more than three stand-alone websites as sources (i.e., websites not linked to a professional organization, journal, or government agency).

Finally, courses like the Physical World necessitate institutional structures that support their cross-disciplinary and integrative nature. It is usually atypical for discipline-focused departments, especially at research universities to recognize the value of cross-disciplinary courses, especially since prospective majors are not the target audience. This can further lead to difficulty in staffing and funding such courses. Furthermore, laboratories and lectures should be taught in the same room and time in order for material to be integrated. However, in many universities, including UIC, it is typical to have a large inflexible lecture room and labs at different laboratory rooms in multiple sections. As a result, lectures and laboratories on a particular subject are often separated by as much as two weeks. In order for integration and building on ideas and understandings to be nurtured, infrastructure changes seem to be necessary.

ENDING NOTE

As increasingly more attention is placed on preparing K-12 teachers, and especially elementary school teachers (as the ones responsible for the first formal educational experience of children), scientists and science educators need to increasingly devote more efforts in thinking about the college science experiences that will contribute to graduating highly qualified teachers. The Physical World course, that we presented in this article, is but one model of such an experience, a course within a set of other science courses that was made possible because of the collective effort of a diverse group of faculty in science and education departments. It is far too early to judge its long-term success, since an important measure of such success is the elementary education graduates' own practice in their K-8 classrooms and their own students' science learning and engagement.

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