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Engaging the community through an undergraduate biomedical physics course

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We report on the development of an undergraduate biomedical physics course at Portland State University, motivated by both student interest and the desire of the university's Physics Department to provide an interdisciplinary intermediate-level physics course. The course was developed through the community engagement of physicians, clinical researchers, and basic science researchers. Class meetings were a combination of regular and guest lectures, hands-on exercises, web-based activities, class discussions, and a student poster information session for patrons at a local science museum. The course inspired students to engage in research projects in biomedical physics that enhance their understanding of science and education as well as benefit the learning of future students. Furthermore, this course offers an opportunity for traditionally underrepresented groups in physics courses, such as women, to gain additional exposure to physics.

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I. BACKGROUND

The biomedical physics course at Portland State University (PSU) was developed to provide an intermediate-level physics course relevant to science majors and pre-health students in particular. As at many other institutions, pre-health majors make up a large fraction (81.3%) of the students in introductory algebra-based physics at PSU.[1] The goal of the biomedical physics course is to provide students with the theoretical background to understand the physical principles of various processes in the human body as well as various techniques used in the medical sciences, such as microscopy, diagnostic radiology, nuclear magnetic resonance (NMR), magnetic resonance imaging (MRI), fluorescence microscopy, and radiation therapy.[2]

There are many reasons why the creation of such a course now makes sense at colleges in the United States and elsewhere. There is growing concern that the United States is not preparing a sufficient number of science, technology, engineering, and mathematics (STEM) students, teachers, and practitioners.[3] Compared to other nations, the math and science achievement of U.S. students and the rate of STEM degree attainment appear inconsistent for a nation that long had been considered to be a world leader in scientific innovation.[3]

In addition to concerns of inadequate STEM education in the United States, several expert panel reports from members of the higher education community have raised concerns about the science content in current pre-health education curricula.[4–6] Pre-health education has been perceived as neither coherent nor well-structured and has been increasingly important given the unprecedented rate of advancements in medical science and technology during the last 50 years (AAMC, IOM).[4,6,7] Furthermore, with the increasing numbers of women and racial/ethnic minorities pursuing medical careers, the development of this biomedical physics course offers a unique opportunity for traditionally underrepresented groups in physics courses to gain additional exposure to physics.[8,9]

Currently, many pre-health course programs require course work in biology, general chemistry, organic chemistry, and physics.[10] Pre-health majors have the option to take algebra- or calculus-based physics. The algebra-based physics courses account for most pre-medicine students; however, since other majors also take this class it does not exclusively focus on material relevant to pre-health professionals.[7] The absence of a pre-health focus results in missed opportunities; for example, although students may be able to describe Compton scattering, the effect of Compton scattering on x-ray image quality may not be discussed within a traditional physics curriculum.

Key technologies not discussed may include several important concepts from the following list: MRI, x-rays, computerized tomography (CT) scans, positron emission tomography (PET) scans, ultrasound imaging, radiation treatment, lasers, and nuclear medicine. A solid understanding of the physics behind these modern medical technologies is important so that physicians will choose the most appropriate diagnostic and treatment modalities, while minimizing extraneous medical costs, radiation doses, and adverse health effects to the patient.[11–13]

Further, to gain admission to a health professions school, students need to earn excellent grades and do well on standardized examinations such as Medical College Admissions Test (MCAT), the Graduate Record Examination (GRE), the Optometry Admission Test (OAT), or the Dental Admission Test (DAT). These examinations may include a physical science section that may not coincide with the learning goals of many physics courses. Consequently, students often experience frustration and consider physics as a required "weed-out" course before entering a health professions school.

Finally, a number of pre-health students who enjoyed their physics course often find no appropriate intermediate-level physics course after the first year. Our Physics of Biomedicine course provides a meaningful alternative to this all-too frequently missed opportunity.[10]

Here, we will describe how this course was implemented at PSU. The implementation of such an interdisciplinary course is at first daunting, but the inclusion of experts found at the university, other research institutions, and medical centers allows physicists that may not be specialists in the biomedical field to prepare such a course.

II. OVERVIEW

In 2007, over 70% of PSU's students completing algebra-based physics stated on their course evaluations that they supported a biomedical physics course.[14] Based on student demand, this biomedical physics course, titled Physics in Biomedicine, was developed as a pilot general elective course for the summer of 2008.

A. Community involvement

Since the concepts taught in this biomedical physics course include complex ideas that are potentially overwhelming to a single university professor, the instructor developed a network with medical doctors, clinical research scientists, biomedical researchers, and other community contacts such as the Oregon Museum of Science and Industry (OMSI). We believe it is possible for other physics instructors to develop similar contacts within their communities. Potential contacts were identified through Internet searches, university colleagues, and referrals from students. Many of these initial contacts were made by a telephone call and e-mail introducing the professor, the course, and desired learning outcomes. In this introductory e-mail, the professor invited the contact to give a guest lecture on their field of specialty. While not all contacts ended up participating in the course, our requests were met with a lot of interest and support. Of those individuals initially contacted, about one third ended up participating in the course. Others cited time constraints, showed no interest, or did not feel comfortable presenting in a physics course. Of the individuals that did not participate, some provided other contacts that resulted in the recruitment of another expert in the same field. Many presenters have returned in subsequent years to lecture to a new cohort of students.

Advanced planning and flexibility are required on the part of the professor to accommodate scheduling restraints. Hands-on activities were scheduled during class meetings when a guest presentation was not feasible. Although it may seem challenging to plan this course a few weeks ahead of course implementation, the major benefit of recruiting specialists from the local community is the establishment of an active interdisciplinary and inter-institutional network of medical professionals, physics educators, scientists, and medical physicists crucial to the sustainability of the course in future years.

B. Curriculum

The course was advertised during the general physics course in the spring term, with flyers in the science buildings and in e-mails sent to pre-professional health list servers. About one third of students enrolled in biomedical physics took this course right after finishing their general physics sequence. The first class was held in the summer term of 2008. Since 2008, this course has been offered annually during summer term and has enrolled approximately 15–20 students per term. Table I outlines a sample of specific topics

Table I. Sample course curriculum. Format key: Lecture (L), Discussion (D), Guest Lecture (G), Activity (A).

Day	Topic	Format	Time (min)
1	**Intro:** Milestones in physics and medicine	L, D, A	130
2	**Ultrasound**, Guest lecture by radiologist specializing in ultrasound	G	60
	Group Discussion: Waves, sound & diagnostic imaging	D	70
3	**Cardiology**, EKG sensor as voltage probe	G, A	130
4	**Poster preparation**, Guest lecture from Oregon Museum of Science & Industry staff	G	60
	Group Discussion, Poster presentation	D	70
5	**Endoscopy**, Guest lecture by gastroenterologist	G	70
	Group Discussion, Fiber optics	D	60
6	**Light absorption by tissue**	A	70
	Physics of Lasers	L	60
7	**LASER eye surgery**, Guest lecture by ophthalmologist	G	60
	Group Discussion, Lasik	D	70
8	**Introduction to Fourier transforms**	L	40
	Fourier Phet activity	A	90
9	**Radiation therapy**, Guest lecture by medical physicist	G	60
	Lecture atomic physics	A, L	70
10	**Gamma Knife**, Guest lecture by surgeon	G	70
	Group Discussion, Gamma Knife	D	60
11	**X-ray**, Guest lecture by radiologist	G	60
	Group Discussion, X-ray imaging	D	70
12	**Computerized Tomography**	G, A	130
13	Small Group Discussion for OMSI poster presentation	D	30
	MRI, Nuclear physics, nuclear spin & momentum	L	60
	Group Discussion, Physics of MRIs	D	40
14	**MRI**, Guest lecture by biologist at MRI research facility, $T1$, $T2$ and relaxation times	G	60
	Discussion, Clinical applications of MRIs	D	70
15	**Fluorescence Microscopy**, Guest lecture by physicist/biologist	G	100
	Group discussion, Microscopy	D	30
16	**OMSI:** Poster Presentations	A	190
	Concluding Remarks, review, post discussion, course evaluations	D	30

for a one-term course with 130 minutes of class time and a 10 min break (the current course format at PSU). Topics varied from year to year based on the availabilities of guest speakers.

The course met five days per week over the three-and-a-half week summer term. PSU operates in the quarter system and the course length is equivalent to a four-credit course that meets twice a week for two hours during a ten-week term. The course was offered to pre-health, biomedical physics majors, and other interested students who had completed one year of general physics. Course activities included (1) lectures given by the course professor, (2) guest lectures from medical clinicians and research scientists, and (3) designing a poster and oral presentation that explains real-life applications of physics principles to patrons of OMSI. The course explored diverse topics including: florescence microscopy, electrocardiography, endoscopy, laser eye surgery, ultrasound imaging, x-ray imaging, computed tomography (CT), and MRI, and is presented in more detail in Table I.

The topics taught in this course during the past four years but not included in Table I include: functional MRI, MRI contrasts, scanning/transmission electron microscopy, voltage clamp, ion channels in cells, laser speckles, pulse oximetry, Epply's maneuver, polymer stents, and optical coherence tomography (OCT).

Course activities included a combination of an introductory lecture by the instructor followed by a guest lecture, hands on activities, and homework activities utilizing interactive homework assignments based on Physics Education Technology (PhET) Interactive Simulations.[15] A number of students who completed either general physics or this biomedical physics course were involved in subsequent years in the development of several of the laboratory and in-class activities, including a light absorption worksheet and a laboratory exercise in computed tomography.[16]

The level of difficulty of the guest lectures varied for the different speakers. Physicians tended to be more advanced in biology, anatomy and physiology, and medicine, while researchers tended to stress advanced math and physics concepts such as how Fourier transforms are used to encode the spatial resolution in MRI images. The course instructor's lectures built on the topics and skills students obtained in the General Physics course. For example, students drew atomic energy level diagrams for a laser and calculated the frequency of the resulting radiation, then later built upon this concept when they drew energy levels of the nucleus to understand why radio waves are used in MRIs. Lectures explored more advanced concepts in atomic and nuclear physics, and connected them to concepts and skills learned in the introductory physics course. Students calculated the magnetic field generated by the superconducting coils in MRIs, and found the number of hydrogen atoms in spin up and down states for different external magnetic fields. While calculus was occasionally employed in the course, the class focused on solidifying mathematical concepts used in an introductory based physics course by giving more advanced applications of these concepts.

Students' grades were calculated from three components: homework, which included conceptual questions from the textbook as well as worksheets with quantitative problems (about 40% of the grade); class participation and attendance (about 25% of the grade); and the oral examination during the poster presentation (about 35% of the grade).

There are multiple books that can accompany this course. We extensively used Suzanne Amador Kane's book *Introduction to Physics in Modern Medicine*, 2nd Edition.[17] The book tended to be at a slightly lower level of difficulty compared to the lecture, and it encouraged students to read independently outside of class. Students' feedback on this book was very positive. This textbook was used, in conjunction with worksheets by the professor, for written homework assignments. Other books used in the course included Paul Davidovits' *Physics in Biology and Medicine*, Tuszynski and Dixon's *Biomedical Application in Introductory Physics*, Benedek and Villar's *Physics with Illustrative Examples from Medicine and Biology*, and Hobbie and Roth's *Intermediate Physics for Medicine and Biology*—although the last two are more advanced.[18–21]

C. Poster session

For the final examination, students designed a poster and prepared an oral presentation explaining real-life applications of physics principles to patrons of OMSI in Portland, Oregon. The poster presentation was an opportunity for these students to practice communication skills by explaining the technical features of a particular aspect of biomedical physics. OMSI is a non-profit scientific, educational, and cultural resource center dedicated to improving the public's understanding of science and technology. OMSI houses many hands-on exhibits for topics including the natural sciences, such as chemistry, geology, physics, human development, lifestyle issues, and technology.[22]

Early in the term, a representative from OMSI visited the class and presented the fundamental steps of designing an effective science poster and engaging museum visitors. One of the most important ideas taught was to "develop a hook," or an attractive title, to attract an individual to the poster. Other crucial design elements discussed during this class meeting included how to cite references, use pictures, and employ a hands-on demonstration in order to engage visitors.

For the poster presentation session, the class was divided into two groups: a two-hour morning session followed by a 2 h afternoon session. The morning group spent an additional hour looking at their peers' posters from the afternoon session using student poster evaluation forms created by the course professor. These forms assessed poster content, organization, and scientific accuracy. Other considerations included both the visual and oral presentation. The second group would arrive 1 h prior to their presentation period in order to complete these evaluations for posters presented during the morning session. Students were required to complete a minimum of four poster evaluations to fulfill the attendance and participation requirement for this class meeting. Their feedback was not used for grading, but we considered it a valuable experience for the students.

In addition to the student evaluation forms, posters were evaluated on a similar grading rubric by OMSI representatives, physics instructors, physics graduate teaching assistants, local science high school teachers, and former students who had previously completed the course. These evaluations were considered for grade assignment.

Poster sessions from prior years allowed the professor to determine the chosen timeframe that had the largest volume of visitors, typically from 10:00 a.m. to 2:00 p.m. After the completion of the poster information session, the posters remained on display for two days in the feature exhibit hall for the benefit of patrons.

Table II lists a sample of poster titles from students during the first four years of the course. Certain topics that could be classified in two categories were listed only once, such as radiation therapy. Radiation treatments still in the experimental phase were categorized as "biomedical research."

Students relished the opportunity to discuss their topics with visitors to OMSI. Many students revealed on course evaluations that the poster session was one of their favorite assignments. Other students wrote that the poster session "emphasized communication skills needed for their future health profession." Patrons who visited the exhibit expressed in surveys that they felt that the posters were appealing to look at, organized, and were very clear and easy to understand.

III. COURSE EVALUATION AND DEMOGRAPHICS

From 2008 to 2011, course enrollment included slightly more female students (52%) than male students (48%). Compared to other upper-division physics electives, in which the students are often more than 80% males, this represents a much larger proportion of females. From the 2009 to 2011 cohorts, 40 students completed a demographic survey, whose results are presented in Table III. Students were predominantly upper-classmen and post-baccalaureate students. The majority of students were biology majors (35%), followed by general science (15%) and physics majors (15%). Sixty-eight percent of students were pursuing a career in medicine, while a smaller proportion of students were pursuing a career in research (12%).

Summative student evaluation data is presented in Table IV. The majority of students (23, or 58%) stated that they "strongly agreed" with the statement that they had gained a better understanding of physics concepts after completing the course. In addition, students reported that they felt less apprehensive about enrolling in additional physics courses. A majority of the students (22, or 55%) completing the course said they would read more physics-related books and articles.

Four students (10%) disagreed with the statement that they would consider taking additional physics classes after completing the course. An equal number of students remained apprehensive about physics classes and said they would not read physics-related books after completing the course. However, for the majority of students, this course was a positive experience that sparked motivation for continued study.

Table II. Sample student topics for OMSI poster session.

Radiation & Radiology
Does it Matter, Or Is It Anti-Matter? (Positron Emission Tomography)
SPECT: Single Photon Emission Computed Tomography
Fighting Cancer with Protons
The Gamma Knife
Nuclear Bone Scan: Looking at Bones Using Radionuclides
X-Ray Imaging
If Radiation Can Cause Cancer, How Can It Cure It?
Breast Cancer Screening: Early Detection Saves Lives
Catch a Wave this Summer! (UV radiation and skin cancer)
CT Angiography: Diagnosing Heart Disease with a Pin Prick
Baby's First Picture! The Physics of Ultrasound Made Easy!
Can You See Using Sound? (How sound reflections allow us to "see" things)
MRI: How Magnets Take Pictures
Optics
LASIK
Fiber Optics in Laparoscopic Surgery
Tooth Whitening with Light. Fact or Farce? The Debate Rages On
Photodynamic Therapy (Healing with Light)
Adjustable Glasses
First Blind People Try the Artificial Eye
Biomedical Research
Radiowaves: Innovative Cancer Treatment of the Future
Treat Cancer with Gold
The Future of Cancer Treatment: Plasmon Resonance
Get With The Flow! The Nitty Gritty About Flow Cytometry
Voltage Clamp: The Tool That Sparked The Beginning of Neuroscience
Functional MRI: The Machine that Can Read your Mind
Potpourri
Shocking, Isn't It? (Defibrillation and Cardiac Arrest)
Electricity Can Relieve Chronic Pain
EKGs: Measuring Electricity of the Heart
Electrical Storms in the Brain
Bionics: We Have The Technology
What Dolphins and Multiple Sclerosis Have in Common
Speak Up! The Physics of Speech Production

IV. DISCUSSION

We have described the development of a biomedical physics elective course at PSU, and reported demographic characteristics and evaluation results for three summer term

Table III. Student demographic data, 2009–2011.

Characteristic	No. (%)
Year in College	
Freshman	1 (2.5)
Sophomore	2 (5.0)
Junior	8 (20)
Senior	19 (47.5)
Post-baccalaureate	9 (22.5)
Other/No response	1 (2.5)
Major	
Biology	15 (37.5)
Biochemistry	2 (5.0)
General Science	7 (17.5)
Health Science	2 (5.0)
Nursing	1 (2.5)
Physics	5 (12.5)
Non-degree: pre-medical, pre-pharmacy	4 (7.5)
Other/No response	4 (10)
Career aspirations	
PhD[a]	8 (20.0)
Medicine	27 (67.5)
Other[b]	2 (5.0)
Don't' know	3 (7.5)
Total	**40 (100)**

Note: Not all enrolled students completed a course evaluation, which accounts for the discrepancy in the number of completed evaluations.
[a]Biology, chemistry or physics (2 students), physics (4 students), neuroscience (2 students).
[b]Biomedical engineering (1 student), forensic science (1 student).

Table IV. Summative student evaluation responses, 2009–2011 ($N = 40$).

	Strongly agree %	Agree %	Neutral %	Disagree %	Strongly disagree %	Response mean (Range), Standard deviation
I gained a better understanding of physics concepts.	57.5	27.5	10.0	0	0	4.50 (3–5), 0.85
I would consider taking advanced physics classes.	47.5	12.5	25.0	10.0	0	4.03 (2–5), 0.69
I feel less apprehensive about physics courses.	47.5	12.5	32.5	0	2.5	4.08 (1–5), 1.10
I would read physics-related articles and books.	55.0	20.0	17.5	2.5	0	4.34 (2–4), 0.88

cohorts of student enrollees from 2009 to 2011. The majority of students reported aspirations toward a career in clinical medicine or to pursue a graduate science degree.

Traditionally, females are underrepresented in physics courses after completion of high school.[23] This course holds the potential of increasing the likelihood of having women continue enrolling in intermediate-level physics courses.

Many students enrolled in the course were upperclassmen or post-baccalaureate students. This is consistent with the fact that general physics is a prerequisite to this course. The demographics of the enrolled students have been consistent with the nationwide trend of an increase in non-traditional students applying to medical school.[24]

A significant proportion (38%) of students in the course were pursuing a biology degree. Although the largest proportions of biology majors were applying to medical school, a few were considering other career paths, such a neuroscience and forensic science. At PSU, this course was offered as an upper-division elective for undergraduate students in biology or physics, demonstrating the support of both the biology and physics departments for this interdisciplinary course.

A positive outcome of this course was subsequent engagement of students in research projects involving the development of further educational material in biophysics. Six former students of biomedical physics and four general physics students are currently working on projects with the professor. Activities developed by these students on MRI, pulse oximetry, and CT have been used in the class and have been published and made available to the wider community.[16,25,26] Five former students started volunteering at OMSI as a result of being involved in this course.

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