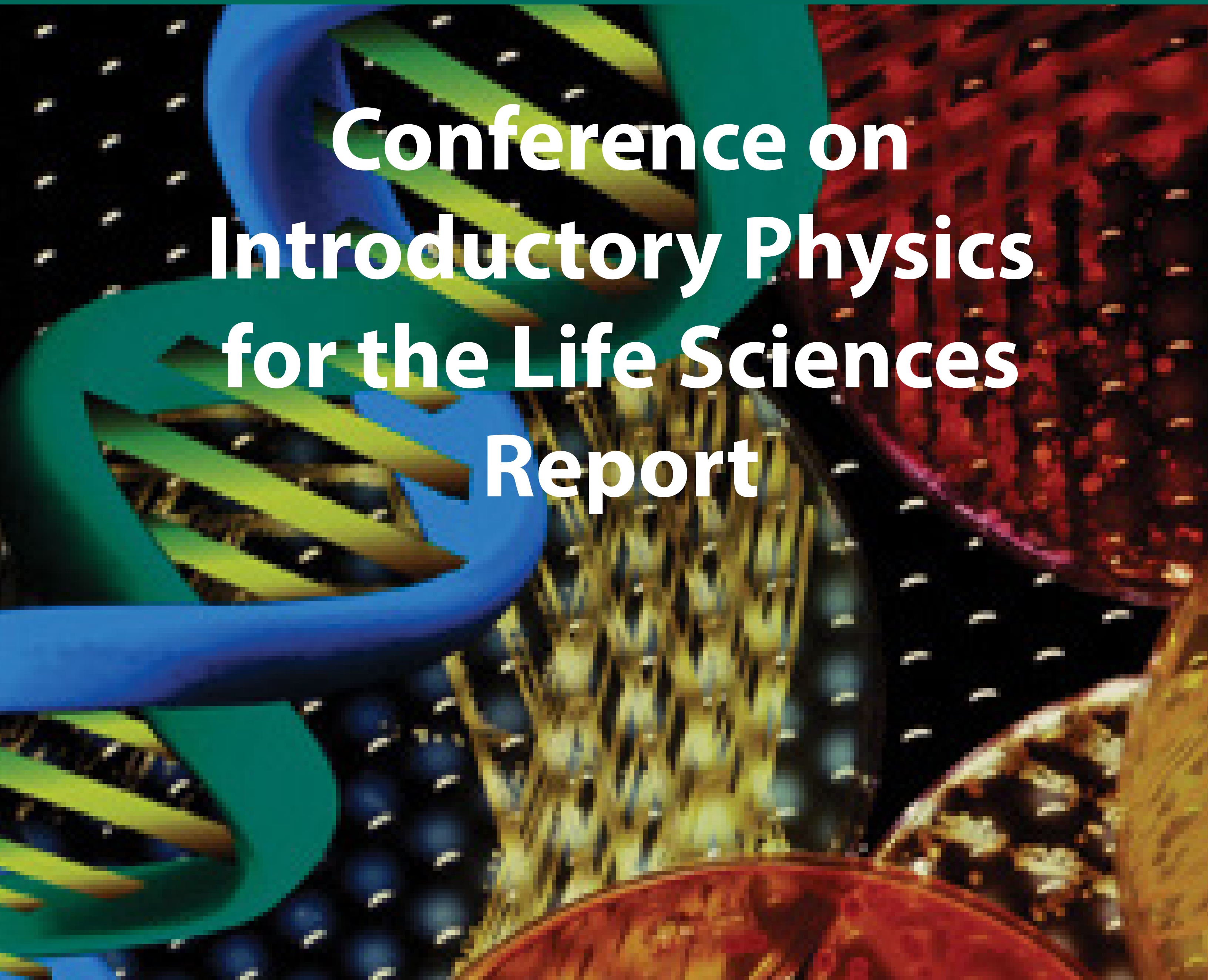
Conference on Introductory Physics for the Life Sciences Report



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I. Executive Summary

In March 2014 the American Association of Physics Teachers (AAPT) with support from the National Science Foundation hosted the Conference on Introductory Physics for the Life Sciences (IPLS). The purpose of the conference was to discuss ways to enhance introductory physics courses taken by life science students, to make recommendations to the physics community to enhance IPLS courses, and to nurture and expand the IPLS community, a network of faculty and administrators working to enhance the physics curricula used to prepare life science students and scientists. Through discussions in working groups and reflection on the plenary talks, the 161 participants (mostly physics faculty members with a few biology and chemistry faculty members) developed the following recommendations:

- ***The IPLS course should, at its core, be a physics course.*** The structure of the course should be organized by key physics principles. "Thinking like a physicist" skills (e.g. modeling, problem solving, estimating, using multiple representations, using data and theory to inform each other) should be taught and practiced.
- ***This physics backbone must be informed by the needs of life scientists***, both in what topics are covered and what biology applications are presented. For example, diffusion, viscous flow, and entropy are key topics for biologists that are often not covered in traditional introductory physics courses. **Working with local life scientists and biophysicists, therefore, is essential to making meaningful reform.** Developing a deep connection to the life sciences will maximize the impact that this course has on the careers and thinking of life science students.
- ***The course needs to be built on best pedagogical practices.*** We have learned a great deal about how to improve teaching and learning in introductory courses, and making the content more relevant is, by itself, not sufficient to ensure deep learning.
- ***To ensure that planned reforms are carried through and sustained, the whole department must be involved at some level.*** The department should work toward consensus on goals for this course, how to assess those goals, and how to reform the course so that those goals are likely to be achieved.
- ***The national IPLS community should support IPLS reform work by providing an online database of curricular resources and assessments, workshops and talks at AAPT conferences and other venues, and creating an online community.*** There has also been a call for AAPT guidelines on making the case for IPLS reform, topical coverage, and textbooks.

In addition, several challenges were identified by the conference participants:

- ***There is a wide diversity of IPLS students.*** The needs of students who will be microbiologists vary greatly from those who will be physical therapists. Students also differ in mathematics, chemistry, and biology background. These differences must be taken into account as IPLS courses are transformed. Also, at many institutions, the course for life science students is often taken by students with majors not in the life sciences. One implication is that **there is no "one-size-that-fits-all" IPLS course.**
- ***There are epistemological differences between biology and physics that both scientists and educators must navigate.*** In particular, biological systems are often irreducibly complex while physicists often employ very simple models. Also, physics tends to be more quantitative than the life sciences. Conversely, biology uses qualitative evidence about the complexity of living systems more broadly and with greater strength than physics tends to. Physics course reformers, with the help of life science colleagues, need to be aware of these differences in the design of course outcomes and course activities.
- ***Reflective, innovative, rigorous teaching is a demanding task but it is not always recognized as an appropriate scholarly activity for faculty.*** A key recommendation of the *Vision and Change in Undergraduate Biology Education* report (see Appendix A) is that faculty should be recognized for the time and expertise that effective teaching requires. Defining curricular objectives, developing course materials, and designing learning experiences are just a few of the manifold tasks of preparing, implementing, and evaluating a course. They all involve time, scholarly judgment, and preparation. The *Vision and Change* report calls on institutions of higher education to recognize and reward faculty for their activities as educators.
- ***Comprehensive course reform will require resources.*** Faculty who take on the work of a comprehensive IPLS reform effort need departmental support: for example, freeing up time through reduction of other responsibilities and providing summer salary and professional development opportunities. It is important to have colleagues to help make hard curricular decisions. Significant reform also requires money for lab equipment, permission to make changes slowly and carefully, and enthusiastic and interested support of colleagues to sustain the difficult work over several years. Faculty members also need the support of the national IPLS community in sharing effective curricular resources.

As a community, we have already taken many steps toward IPLS course reform and the IPLS conference was influential in furthering IPLS reform at many institutions. The conversations among participants clarified key arguments, principles, challenges, and action items necessary for reform. Several collaborations were initiated because of the conference and a number of Physics Education Research (PER) groups have identified key areas for further study and development. In the IPLS Conference follow-up survey (See Section VII) many participants report that they have made meaningful progress toward their reform goals.

At the national level, several key action items will require additional funding to make significant progress. However, AAPT and the IPLS community within AAPT and the American Physical Society have already begun acting on those items that can be addressed with current resources. A collection of course syllabi and resources was gathered and is being archived and made widely available (See Appendix A for a list of resources). In addition to the IPLS Conference website (www.compadre.org/ipls/) other digital resources on ComPADRE, the physics digital library, will be collected. A test site for an IPLS portal that can serve as an archive and clearing house for curricular materials is being developed. AAPT has identified a group who will maintain oversight of the IPLS presence by organizing sessions and workshops at AAPT national meetings.

II. Background: The need for change

Over the past decade, there has been considerable attention paid to the undergraduate education of life science majors, targeting both students who intend to pursue basic research careers in the life sciences as well as those who aim for professional education in medicine and other health-related fields. Reports from a number of professional organizations (see Appendix A) emphasize the increasing importance of the study of the basic physical sciences and mathematics for these students, given the changing nature of research in the biological sciences and the changes in the clinical practice of medicine and other health-related fields. In all of these fields, a solid grounding in the basic sciences is now considered essential to be a successful professional, able to keep up-to-date in fields that are changing dramatically in their knowledge of the basic mechanisms of life, health, and disease.

According to the American Institute of Physics (AIP) Statistical Research Center, about 200,000 life science students take a year of college-level introductory physics each year, either as a requirement for a biology degree or to meet the admissions requirement of 93% of U.S. medical schools [AAMC 2014] and other health-related professional programs. About 32% of those students take those courses in two-year colleges. But in many cases the students do not see the direct relevance of what they have learned in their physics courses for their future careers since few introductory physics for the life sciences (IPLS) courses are designed specifically for life science students. Traditional IPLS courses often consist of the (more or less) standard set of introductory physics topics, used in courses for engineers and physics majors, but with the mathematical background adjusted to fit the preparation of the life science students. A common argument has been that life science students should simply take a "straight" physics course in which they learn fundamental physics concepts and problem-solving skills. It is then up to the students to apply those concepts and problem-solving skills to whatever STEM field they pursue.

Such a situation does not serve the students well. Education research [Ambrose, et. al 2010] has shown that most students have difficulty applying what they have learned in a science course to areas different from that in which the original learning occurred. For example, students may learn about energy conservation in physics in terms of projectile motion and collisions, but then have difficulty in applying (or even recognizing the applicability of) that principle in understanding the dynamics of living systems, where thermal energy and chemical energy play major roles. If the goal of an IPLS course is to have students be able to apply physics concepts to the understanding of living systems, we need to give the students the opportunity to do so.

In offering the life science students a straight physics course, we are missing a unique opportunity to make a significant impact on how future life science practitioners use physics and quantitative reasoning as they think about living systems. By making explicit connections between physics and biology, students can come to understand organisms at a deeper level, in a qualitatively different way. We also have the opportunity to improve their confidence and ability to use quantitative approaches where useful.

These issues are not new and the physics community has discussed ways to enhance IPLS courses for several decades. A 1975 report [French and Jossem 1975] focused primarily on content in physics courses taken by life science students. More recently, George Washington University, with NSF support, hosted in 2009 a one-day gathering of about 50 physics faculty members to discuss possible changes in IPLS courses to meet the needs articulated by the life science community in the reports cited previously. In addition, sessions and workshops focusing on IPLS courses have been held at the Summer and Winter meetings of the American Association of Physics Teachers (AAPT) for the last six years. But it was soon recognized that a large conference was needed to bring together the physics faculty members who have undertaken or wish to undertake enhancement of IPLS courses, to survey what has been done and what future work is needed to enhance the effectiveness of IPLS courses.

The main purpose of the March 2014 conference was to create a community of people interested in enhancing IPLS courses. This community includes biologists, physics faculty members who have been active in developing effective IPLS courses, physics faculty members who have plans to work on IPLS courses, and experts in science education research. This report summarizes the many discussions held during the conference and provides recommendation for actions by the IPLS community.

III. The Conference Schedule and Structure

The conference was held March 14-16, 2014, at the Key Bridge Marriott Hotel in Arlington, Virginia. It was co-sponsored by NSF (1322895) and AAPT. The list of conference organizers is in Appendix C, along with plenary speakers and the complete conference schedule. Four Working Group sessions in which attendees and presenters discussed the following issues formed the core of the conference:

- Course transformation and learning goals
- Identifying strategies and resources needed for IPLS course transformation
- Take-home ideas from the conference presentations
- Formulating recommendations for further work on IPLS courses

This report includes a summary of these discussions. Resources from the conference (e.g., plenary talks and IPLS course syllabi submitted by participants) are located on the ComPADRE (the physics digital library) site for the conference http://www.compadre.org/ipls/. Appendix B gives a detailed list of recommendations.

There were 161 participants at the conference (a description of participants can be found in Appendix D). They were primarily physics faculty members who were knowledgeable about the challenges in teaching the IPLS course, about physics education research results, and about active learning techniques. Most (85%) had taught IPLS courses recently or were planning to teach one in the near future. About 1/3 of the participants reported that their departments supported reforming the IPLS course. Many, however, came from departments that were unaware of the need for change (about 50%) or had negative or mixed reactions (about 10%) to proposals for change.

Prior to the conference, the IPLS Conference Planning Committee collected information to provide a comprehensive "State of the Community" snapshot of the current curricular practices and reform efforts for the IPLS course. The resource collection of Appendix A contains that information along with other resources that should be useful to faculty members working on IPLS course redesign.

IV. Life Scientists' Perspectives

Several of the invited plenary speakers were life scientists who offered their perspectives on the educational interface between the life sciences and physics. Ideas emphasized by the life science speakers included the following:

- Physics is essential to understanding biological systems because physics principles constrain and enable the work that organisms must do [Committee on Biology Education, 2003] [Brewer and Smith 2011].
- Many physics topics valuable for the life sciences are not covered at all in most IPLS courses, or they are covered with insufficient depth, or with inappropriate focus. These topics include diffusion, osmosis, fluids, entropy, enthalpy, and electrostatic forces at the microscopic level.
- Modeling, quantitative analysis, and computation are becoming essential in almost all areas of the life science. Physics courses provide an ideal venue for learning those skills.
- Life scientists can help students see the value of physics to the life sciences in two powerful ways:
  1. By explicitly making connections between students' life science knowledge and physical principles in their life science courses.
  2. By communicating the value of the IPLS course for future life scientists to both students and instructors, both in general and by identifying specific topics and skills for students to master.
- Life scientists can work with physics faculty members to enhance the effectiveness of IPLS courses. Having physicists work with local life scientists is key to effective course reform.
- Many life scientists are reforming their own pedagogy by focusing on cross-cutting ideas and interactive engagement methods and can serve as both collaborators and supporters for physics faculty members who are enhancing their IPLS courses.
- The new Medical College Admission Test (MCAT) (appearing in spring 2015) (https://www.aamc.org/students/applying/mcat/mcat2015/) will test students' ability to use their scientific knowledge and skills to answer questions about living systems. This focus is in alignment with the new emphasis on competencies (rather than courses) recommended for entrance to many medical schools. IPLS courses can provide additional opportunities for students to develop these competencies.
- Preservice high school biology teachers (who will likely take the IPLS course) will influence many future generations of students. The IPLS course can positively influence the content and pedagogy of their classrooms:
  - These teachers impact the formation of student perspectives and interests by preparing the next generation of STEM students to be ready for cross-disciplinary work at the university level and beyond. Therefore it is imperative that the preservice high school teachers themselves are provided with a strong exposure to the importance of physics to the life sciences.
  - Interactive engagement pedagogies are essential parts of effective teaching. Preservice teachers will profit from seeing such pedagogies in action, not only in their biology courses (as promoted by the *Vision and Change* report), but also in physics.

V. Conference Presentations and Working Group Discussions: IPLS reform

Four broad themes in how the IPLS course needs to be reformed emerged from both the presentations and the Working Group discussions:

A. ***Select the most appropriate content for the course, taking into account the particulars of the institution and its students.*** Simply teaching, whether with or without calculus, the same topics and examples used in the physics course for engineers or physics majors, gives short shrift to many topics of critical importance in the life sciences while using up valuable time on topics that are less relevant for the intended audience.

B. ***Design the course to develop students' understanding of physics principles and core scientific skills, including skills in quantitative problem solving and data analysis.*** Indeed, the quantitative skills that are naturally developed and practiced in studying physics are just as important for life science students as an understanding of the physics content.

C. ***Use effective interactive engagement pedagogy and set well-defined learning goals that challenge students to develop higher-level thinking skills.*** A common theme in the calls for reform has been the need to educate students in thinking critically, reflectively and being able to assess the limits of their understanding more effectively.

D. ***Take into account epistemological and contextual differences between physics and the life sciences.***

E. ***Follow successful models for implementing lasting curricular change.*** Course reform, if not done thoughtfully, can quickly disappear once the "champions" no longer teach the course, or the proposed changes may never be implemented at all. Paying attention to the four previous themes, engaging the department to build a consensus on course goals and assessing student outcomes are key to long-term sustainable and effective change.

In the following, we elaborate on each of these themes.

A. Select most appropriate content

Any physics course for life science students must be anchored in core physics topics, including Newton's laws, conservation laws, electromagnetism, thermal physics, and quantum physics. Selecting the most appropriate content and applications for life science students requires some disciplinary expertise in the life sciences and allied health fields. Most physics faculty do not have deep expertise in the life sciences so conversations with faculty colleagues in life science departments and careful reading of life science policy documents (see Appendix A) are essential to the reform process. Physics faculty can most effectively teach a course when they feel comfortable with the content and are enthusiastic about engaging the students, so it is critically important to leverage local partnerships to support physics faculty in teaching IPLS courses and in selecting those topics that play to the instructor's strengths.

In selecting examples of physics applications in the life sciences, we argue that the instructor should use "authentic biological examples," that is, examples where physics allows for a deeper understanding of the living system. A kangaroo sliding down an inclined plane does not obviously lead to a deeper understanding of the kangaroo as a living system. Again, we emphasize the importance of consulting with life science colleagues to develop those authentic applications.

One of the challenges in teaching an IPLS course is the tremendous diversity within the life sciences and the allied health fields: many large universities have an entire School of Biological Sciences as well as additional schools related to agriculture, forestry, etc. The allied health fields include not only medicine but also physical therapy, kinesiology, and exercise science, to name just a few. As an example, we note that researchers in molecular biology and biochemistry deploy a very different set of physics concepts than do physical therapists and animal physiologists. Entropy is very important to the first group, rigid body statics and dynamics to the second. A topic such as torque is important to both; at the microscale, torque is important in understanding the locomotion of small organisms, the behavior of small molecules, and the structure of solvation shells formed by water (dipolar) molecules, for example. At the macro level, torque is crucial for understanding muscular and skeletal statics and dynamics.

Which content is most appropriate to a particular institution's IPLS course depends on the student population in the course and what kinds of courses students will take after the IPLS course. This diversity of areas also produces a problem in finding appropriate textbooks suitable for a particular local situation. Many conference participants said that the lack of appropriate textbooks was a major barrier to their reforming their IPLS courses.

Another challenge is that in many institutions, the course taken by life science students is also taken by students with a variety of majors: technology, architecture, general education, etc. This diversity is especially notable in smaller colleges and community colleges. For such courses, it will be a significant challenge to decide on the optimal mix of topics and applications that will be of value to all students. As mentioned previously, the challenge in choosing appropriate topics is exacerbated by the difficulty of finding a textbook with the appropriate mix of content to meet the needs of an institution's set of IPLS students.

For all of these reasons there is no "one-size-fits-all" IPLS course; the best IPLS courses tap into the local institutional particulars to help students build connections between their life science studies and physics. That said, we note that the conference participants repeatedly highlighted several topics that are crucial in the life sciences but are frequently neglected in introductory physics:

- Fluid statics and dynamics
- Statistical phenomena (diffusion, osmosis, radioactive decay)
- Energy as manifested in biological systems (open systems, chemical reactions, and thermal energy as well as potential and kinetic energy)
- Imaging modalities used in the biological sciences and medicine
- Electrical interactions in an aqueous environment

The challenge is to design IPLS courses that include these topics in significant ways while still remaining faithful to physics core disciplinary concepts and physics scientific skills.

The conference participants had vigorous discussions about what standard introductory physics topics might be eliminated or treated with significantly less detail than in the traditional introductory physics course for physics majors and engineers to make time for life science oriented materials. Among the many suggestions were reduced discussions of 2D and 3D kinematics, angular kinematics and dynamics, planetary orbits and universal gravitation, and heat engines. But all agreed that detailed decisions should lie with the individual instructor. The course syllabi submitted by the conference participants (www.compadre.org/ipls/syllabi) display a wide range of such choices.

B. Develop core scientific skills, particularly quantitative skills such as modeling, problem solving (broadly construed) and data analysis

Undergraduate science education reform increasingly calls for instructor attention to helping students develop scientific skills explicitly, rather than assuming that skill development will automatically accompany the learning of content. For a physics course, these skills can be grouped under the general category of "thinking like a physicist," and the development of these skills is one reason why biologists ask their students to take physics courses. While a single IPLS course cannot include all possible content topics of interest, by developing strong reasoning skills and practicing the application of core physics disciplinary concepts to life science situations, students will be well prepared for future learning.

We now discuss several of the scientific skills that were mentioned frequently during the conference. These skills, of course, apply equally well to other physics courses including the introductory physics courses taken by engineers and physics majors.

Expert physicists and other quantitative scientists use mathematics to make meaningful statements about the natural world. Students, on the other hand, often view mathematics as a collection of formulae, and using mathematics consists of simply choosing the appropriate formulae and inserting numbers to obtain a result. Appropriate work in a physics course can help students develop the skills associated with "reading" equations and understanding the physical meaning conveyed by equations.

One of the strengths of physics is its emphasis on reasoning about the world based on a few fundamental quantitative principles. That kind of reasoning is relatively rare in the life sciences, where the focus is often on understanding qualitatively the variety and diversity of structures in living systems. However, contemporary biology is becoming more like physics in deploying general principles (often from physics and chemistry) to understand living systems, particularly at the molecular level. IPLS courses can help life science students see the importance and utility of reasoning based on fundamental principles and learning how to apply those principles in a wide variety of situations. Those fundamental principles also provide a framework to organize a vast array of information about living systems. An IPLS course can help students recognize the most important physical processes at work in a system and how to use those principles to create physical and mathematical models of complex situations. In addition, students can learn to recognize the assumptions and approximations used in those models. Students can also develop the skill of using multiple representations (diagrams, graphical displays of data, mathematical expressions, computer simulations, etc.) to understand physical processes.

Physics also provides a useful framework for students to learn to use scaling/functional relations to predict how one quantity will change in response to changes in another even for non-linear functional relationships, and even if proportionality constants are unknown. Scaling relationships and dimensional analysis are tools that all scientifically trained workers should master.

An IPLS course can also give students practice in evaluating the reasonableness of quantitative answers and the validity of simplifying assumptions, evaluating uncertainty in quantitative data, understanding what conclusions can be drawn from data based on the uncertainties, and arguing from evidence about the conclusions drawn from experiments and mathematical models.

The laboratory components of an IPLS course can provide practice in designing experiments to answer a question about the physics of a living system and in quantifying the physical processes in a biological system.

By focusing explicitly on these essential thinking skills in the course design, IPLS courses will be perceived as different from, but no less rigorous and challenging, than physics courses for engineers and physics majors.

C. Use effective pedagogy, including explicit, well-defined learning goals that challenge students to develop higher-level thinking skills

Learning goals are broad statements about what students should learn in a course and what they should be able do with that knowledge. The IPLS course should take full advantage of all of the physics education research community's accomplishments in developing an understanding of and the mechanisms for enhancing student learning in physics courses. These mechanisms include using not only the PER community's now well-established pedagogical approaches (active learning, attention to conceptual understanding, attention to beliefs and attitudes—see Appendix A for references), but also practices from the broader higher education community, such as presenting learning goals clearly to students, and designing those learning goals to engage students' higher-level thinking skills.

The key lesson from PER is that faculty members need to focus on what students are actually learning and not just on what is taught. This idea is particularly important for IPLS courses because the physics community (including most faculty) are only slowly becoming aware of key differences between how life science students understand and pursue science and how we as physicists expect them to function in our courses. Often life science students have a mistaken model that learning science is only about learning information, and hence expect learning physics to be about memorizing definitions and identifying the right equation to solve a problem. Clear learning goals, in tandem with organizing the course around problems (both conceptual and quantitative) that require synthesis of several ideas, can help students develop a more sophisticated and robust understanding of learning.

From the discussions at the conference and from the post-workshop survey in which participants were asked to indicate their goals for an IPLS course, we have distilled a set of recommended learning goals. The vast majority of goals listed were variations on the following, with cognitive goals comprising the majority of comments.

Cognitive goals:

1. Students can reason with quantitative physical ideas and principles.
2. Students can use physics concepts to explain physical phenomena.
3. Students can apply physics principles and concepts to explain biological phenomena.

Skills and habit-of-mind goals:

1. Students should be able to "think like a physicist," i.e. they use problem-solving strategies, analytical tools, conceptual understanding, and fundamental physical principles to reason about biological problems.
2. Students should be able to demonstrate quantitative and modeling skills, including being able to read and interpret graphs, make reasonable assumptions, etc.

Affective (beliefs and engagement) goals:

1. Students should be able to describe the many ways in which physics constrains and enables life and recognize knowledge of physics as an important tool for the life sciences.
2. Students should be able to articulate the large organizing physics principles (e.g. Newton's laws, conservation laws) and to use them to organize their thinking about physics problems.
3. Students should demonstrate an increased confidence in their mathematical reasoning skills, as well as their propensity to use quantitative arguments. They see equations as telling a story in addition to giving a number.
4. Students should understand that mere memorizing is not learning.

D. Take into account epistemological and contextual differences between physics and the life sciences

There are epistemological differences between biology and physics that both scientists and educators must navigate. In particular, biological systems are often irreducibly complex while physicists often employ simple models. The simple model strategy is an important contribution that physics can make to the understanding of living systems. Examples include models for the relative sizes of branching vasculature (Murray's law) and for the (more or less) universal size of biological cells. However, many life science students, and even life science faculty, are not accustomed to that way of thinking about living systems. Physics faculty will need to spend some time illustrating the power of simplified models to convince life science students that such models indeed help us understand living systems.

Even fundamental concepts such as energy are used differently in physics and the life sciences. Physicists often focus on isolated systems in thermal equilibrium while life scientists focus on systems that interact with their environment and are far from equilibrium. These differences lead to different ways of talking about the conservation of energy and energy transfers [Meredith and Redish 2013]. IPLS course instructors need to be aware of and take into account these contextual differences.

Also, physics tends to be more quantitative than life science. Conversely, biology uses qualitative evidence about the diversity of living systems more broadly and with greater strength than physics tends to. Physics course designers, with the help of life science colleagues, need to be aware of these differences in constructing course outcomes and course activities.

E. Follow successful models for implementing lasting curricular change

There was widespread agreement that reforming the IPLS course as described previously is not trivial; it requires a great deal of time and expertise to develop appropriate materials. It is challenging to teach a course reformed in this manner even if all the curricular materials are provided, because the course draws on some non-standard physics topics. Curricular and pedagogical resources, as well as faculty time, are critical to support such reform.

High-quality, readily available, and easy-to-use materials with faculty support information will be essential for widespread reform of IPLS courses, including good textbooks (or textbook equivalents). Due to the need to tailor the course to local populations and character, it was agreed that materials need to be fairly modular and any book needs sufficiently broad coverage to be adaptable to local needs.

At many institutions, the only realistic (and often the best) approach to IPLS reform may be a gradual one, perhaps by beginning with the revision of a few instructional labs, or by incorporating a few biologically authentic applications into the course.

Several conference participants described innovative courses for life science students, including interdisciplinary courses taught jointly with life science or chemistry faculty members, for example. We encourage physics departments to think broadly about innovative approaches to teaching physics for life science students.

For course reforms to be sustained, department- and even institution-level change is required (see Appendix A). One way to motivate institution-level change is to point out that IPLS courses serve a large student population and to note the disciplinary reports from the life sciences and medicine that call for reform. The Carl Wieman Science Education Initiative offers a model [http://www.cwsei.ubc.ca/resources/files/CourseTransformationGuide_CWSEI_CU-SEI.pdf] for such course reform.

Based on discussions among conference participants, we provide a short set of talking points for conversations that physics faculty can use in discussions with their departments, chairs or deans about IPLS course reform.

1. *Why reform the IPLS course?*

- A "straight" physics course with standard topics and little or no mention of the life sciences does not help students see the role of physics in constraining and enabling life.
- Life science students will struggle to connect biology and physics on their own as the connections are obscured by different vocabularies and different contexts.
- We are missing an opportunity to make a significant impact on the thinking of life science students. The physics and quantitative perspectives can qualitatively change how life science students think about how organisms accomplish their goals.

2. *What data are needed for change?*

- Who are the students in the IPLS course? What are their majors? Their career plans? Their mathematics, physics, chemistry, and biology background? Are there many students transferring in or out of our institution? Are there non-life-science students in this course?

3. *What processes and resources will support lasting change?*

- Collaborating with life science faculty and students as key stakeholders in the IPLS course.
- Discussing course learning outcomes with physics faculty to create departmental consensus.
- Using interactive-engagement pedagogy.
- Gathering and using evidence of student learning to inform ongoing changes.
- Creating a repository of course materials for use by others in the department.
- Supporting course reformers through release from other duties, providing summer salary, and providing support to hire undergraduate or graduate students to work with faculty members on course reform.
- Making use of Learning Assistants and Teaching Assistants who are trained specifically to work in IPLS courses.

VI. Challenges and Resource Needs for IPLS Reform

During the discussions following the presentations and in the Working Groups, six key elements were identified as particular challenges to reforming the IPLS curriculum.

A. The intrinsic complexity of living systems

Even the simplest bio-molecules are complex compared to the typical systems used as examples and models in traditional introductory physics, where the emphasis is often on point-particle models and systems in which only one type of interaction (e.g. electromagnetism) is considered. The intrinsic complexity of even the simplest living systems means that the physics tradition of focusing on idealized (e.g. friction-free, point-particle) systems is problematic in dealing with living systems. It is a fact of life (pun intended) that understanding the behavior of a living system requires applying concepts at many length and time scales simultaneously and dealing with systems in which many length and time scales are simultaneously important, where friction and viscous forces can never be ignored, and where the active elements of the system are often organized into feedback loops at various levels of complexity. Developing a suite of examples of biologically authentic phenomena where physics principles truly add to the understanding of the system will require a community-wide effort.

B. Tension between teaching core physics concepts and their applications to understanding living systems

As discussed in Section V. A, deciding on appropriate topics for an IPLS course requires input from both physics and the life sciences. Furthermore, in most situations faculty members proposing substantial innovations in an IPLS course must convince their physics colleagues that those changes, which inevitably include a set of course topics different from those in introductory physics for physics majors and engineers, still provide a "rigorous" physics course. One aim of this report is to provide an outline of the arguments that justify content changes in IPLS courses.

C. Breadth of possible biological applications

As mentioned previously in Section V. A, it is important to be aware of different "flavors" of life scientists (molecular and cell biologists, organismal biologists, physiologists, ecologists, botanists, etc. and basic research biologists as well as those in health-related professions), because different fields of the life sciences have significantly different priorities and ways of thinking about the role of physics. For example, molecular biologists need to understand enthalpy and entropy, while physical therapists are concerned with forces applied at the organismal level. Therefore it is important to know your students (their majors, backgrounds, and career aspirations) and to collaborate with the appropriate life scientists to determine which physics concepts are of greatest value for those students. Because of these differences, the IPLS content cannot be completely standardized; the course materials must be adapted to local needs.

These challenges may be exacerbated in two-year colleges, where there is often only one introductory physics course that must service a broad range of students with diverse career interests and mathematical backgrounds. In addition, many two-year college life science students transfer to a four-year institution, so having an alignment between the physics course at the two-year college and the expectations of the four-year institution is important.

D. Choice of appropriate math level

Some IPLS courses use calculus, others use just algebra and trigonometry. Some also use computational tools (e.g., VPython, Excel, Wolfram Alpha) to allow students to work with more complex problems. The challenge is to design an IPLS course suitable for the specific institution while providing the mathematical and computational tools that will allow the students to see the utility of physics in understanding living systems.

The life sciences (on average) are more descriptive and less quantitative than physics, often because the systems studied are so complex, as mentioned previously. So while physics faculty members do want to improve life science students' quantitative reasoning abilities, we need to be constantly aware that the students' perception of the value of, and their comfort level with, quantitative reasoning is different from ours. We also want to reinforce the notion that mathematics is not just about generating numerical results, but that we use mathematics to learn something important about how the world works. For example, we use symbolic mathematical expressions to explore qualitatively how one variable changes when another (or several others) change. If many of our homework and test questions can be answered by "equation hunting," we are not reaching the pedagogical goals articulated previously.

E. Student buy-in is not guaranteed

The new IPLS content (and in some cases the new pedagogy) may well challenge life science students' expectations for a physics course. We must, however, have their willing engagement for the new curricula to be effective. We should not assume that all students will immediately embrace all of our changes. In particular, some students may have a strong focus on MCAT preparation. In fact, the new IPLS pedagogy will be more challenging, more rigorous than many of the present implementations, and those characteristics will help prepare the students for the recently revised (2015) MCAT, which emphasizes bringing concepts in physics, chemistry, and biology to bear to understanding living systems. As a strategy for helping students see the broader usefulness of an IPLS course, faculty members might have the students find online the syllabi of the physiology courses that medical and veterinarian students take in professional school programs. Those courses make heavy use of a wide variety of physics concepts. In addition, the report on the *Scientific Foundations for Future Physicians* [AAMC/HHMI 2009] makes clear the importance of physical science knowledge and quantitative reasoning skills in medical school education, not just in preparing for the MCAT.

Another barrier to buy-in is that students often do not take their IPLS courses until late in their college careers. Hence, biology professors cannot build on that physics knowledge, thus supporting the unfavorable belief that physics is not important to biology.

A set of issues related to student buy-in were formulated by conference participants:

- How do we convince students that the new format is of direct benefit to them?
- How do we get students to alter their approach of study to be in alignment with the new pedagogy?
- How do we get students to engage willingly in greater challenges in critical thinking, mathematical analysis, and quantitative exploration of complex phenomena?
- How do we move students away from the expectation that the IPLS course is only a MCAT prep course?

F. Laboratories appropriate for IPLS

The conference participants recognized that traditional physics instructional labs in introductory courses are often not well suited for a life science student audience. But developing labs that help students see how physics supports the understanding of living systems was thought to be a major challenge by most participants. Some conference participants thought that changing a few instructional laboratories might be an easy place to begin IPLS course reform since they can be changed incrementally.

The first step in such a reform must be a departmental discussion to set the goals of the IPLS instructional labs. Should the labs focus primarily on developing lab skills or developing conceptual understanding or both? And which skills in particular? We note that the American Association of Physics Teachers' recently adopted *AAPT Recommendations for the Undergraduate Physics Laboratory Curriculum*, should be helpful in articulating those goals. The report is available at http://www.aapt.org/Resources/upload/LabGuidlinesDocument_EBendorsed_nov10.pdf.

Many participants felt that IPLS labs should illustrate how physics ways of thinking and carrying out measurements can help students understand living systems and that it is important not to lose sight of the physics way of doing experimental science. There was some concern that the labs might lose their physics focus if too much attention is paid to techniques related to the life sciences.

G. Resources needed for faculty

All of the points mentioned above make it clear that the IPLS community needs to work together to create resources (lab manuals, lectures, topic sequences with a well-articulated rationale, homework, and exam problems) that can be shared and modified as required by local needs. Some of these already exist (see Appendix A). Others, including crowd-sourcing of IPLS curricular materials, are in the planning stages.

Assessments, similar to the Force Concept Inventory and the Force-Motion Conceptual Evaluation but geared to the specifics of the IPLS course and student populations, are sorely needed. These are essential for formative assessment to guide the course reform process and for accreditation purposes. Currently, we are aware of only three IPLS-specific assessments: Maryland Biology Expectation Survey (MBEX) [Hall 2013], a conceptual survey on fluids statics which is still under development [Lindow, Carbone and Wagner 2013], and a conceptual survey on osmosis and diffusion [Fisher, Williams, and Lineback 2011].

Reformers also need the support of their departments and institutions. This support includes time, money, but most importantly collaborators to help make difficult curricular decisions, to bring different viewpoints to the reform process, and to sustain the changes.

Most participants expressed the need for examples of effective IPLS labs along with the associated learning objectives. Once goals for the laboratory are set, further resources are needed. Those discussed at the conference include

- Lab manuals in *editable* electronic form with meta-data: level of students, time allocated to the lab, equipment lists, and pre-lab activities.
- Images, videos, and simulations, along with all the information needed to effectively use/analyze those images, videos, and simulations, form an important supplement to the lab curriculum.
- Examples of IPLS labs that can be done with equipment available in most physics departments.
- Funding agency programs that would support the acquisition of new lab equipment where needed. Some participants pointed out that a physics department might be able to arrange to borrow some life science equipment, such as microscopes, from their local life science departments.
- Life science expertise and time to develop biologically meaningful labs.
- An "apprentice" program like the Advanced Lab ALPhA Immersion program, (http://www.advlab.org/immersions.html) that allows physics faculty members to learn from those who have developed successful IPLS labs.

VII. Summary of the Post-Conference Nine-Month Participant Survey

The following is the executive summary of the post-conference nine-month follow-up survey administered by the project's external evaluator, Dr. Stephanie Chasteen.

The conference appears to have been very influential in furthering IPLS reform at various institutions, mainly by creating exposure and awareness among the participants regarding the need for change, and the diversity of approaches to IPLS courses. Additionally, the conference provided participants with specific resources, the motivation for change, and rhetoric and tools for making a strong case for change at their institutions. Many reported that once they were armed with tools and arguments from the conference they were able to argue more effectively for why IPLS courses need reform, and what the reform might look like.

Many participants have made meaningful progress toward goals stated at the end of the conference and describe additional accomplishments over the past year. One common outcome was modifications within IPLS courses (45% of respondents) — mostly changes to the course topics or to labs. Most courses were not completely redesigned, but rather benefited from small improvements. In other cases, planning discussions about reforming IPLS courses have progressed as a result of the conference.

Additionally, most participants (72%) have collaborated with individuals and departments as a result of the conference. Participants seem to have particularly taken to heart the importance of collaborating with life-science faculty on IPLS reform, with 55% having contacted biology departments. Many participants (32%) report that a main outcome of the conference was a discussion with physics or life science colleagues, often resulting in generating additional interest and engagement in reform at their institution.

The biggest obstacle to change was time—both workload constraints, as well as the fact that change to IPLS courses requires long-term engagement from a variety of partners. Lack of expertise and resources (including good textbooks, or money to transform labs) was another impediment. Several respondents also indicated that they had met with active or passive resistance from other physics faculty, or that IPLS courses simply are not a priority at their institution.

Overall, participants report that the conference was very influential and helpful in their achievement of these goals. In some cases, they would have appreciated more specific resources within the conference, such as hands-on workshops, recommendations for textbooks and topics, and ready-to-use materials. For the future, there is a large stated need for resources and examples to use in IPLS courses, AAPT guidelines on IPLS courses, workshops and webinars, and opportunities to interact with other IPLS colleagues.

VIII. Current and Future National Efforts

ComPADRE IPLS Resources

ComPADRE, the physics digital library, already houses a large collection of resources for IPLS courses. (In particular resources associated with the March 2014 IPLS Conference can be found at http://www.compadre.org/ipls/.) However, this collection of materials has limited use since the materials are distributed throughout the archive and are identified with a system of keywords and indexing that needs improvement. Though the more ambitious elements of the redesign of the IPLS archive in ComPADRE must wait for additional funding, certain aspects will move ahead even with limited financial resources. As a first step, we have compiled a list of currently available resources in Appendix A.

Already under way is the development of a "Physics for the Life Sciences" portal where users will be able to identify and access the resources already on the site and to communicate with other users (though the present networking options are not well suited to the task). The final tagging and indexing will most likely require several years of research, but by standardizing the terms currently used, we will be able to make a significant improvement on the existing collection.

A second step is the preparation of materials and resources that help faculty make the transition from preparing course materials for their individual use to sharing those materials with others in a scholarly way. Some of these resources are already under development by the AAPT Book Editor and modifying these resources will be a way of quickly developing preliminary materials for IPLS needs.

A third step is identifying already developed resources and adding them to the collection. However due to the presently limited resources, the rate at which we can add to the collection is restricted compared to what we envision once ComPADRE has additional funds.

Other resources that have been requested are lists of suggested textbooks and topic coverage. Remembering that each IPLS course is unique, a list of possible topics and reasons for both including and excluding topics would be most useful. Similarly, a list of IPLS textbooks with thoughtful commentary about advantages and disadvantages would be very helpful to all IPLS faculty.

Workshops and sessions at AAPT and APS meetings

Over the last five years the IPLS community within AAPT has sponsored at least two sessions and one workshop at each of the AAPT Winter and Summer national meetings. In addition, the IPLS community has sponsored several sessions at APS national meetings. In order to help focus the efforts of the IPLS community, AAPT's Committee on Physics in Undergraduate Education has established an IPLS subcommittee and guaranteed the subcommittee no fewer than two sessions and one workshop at both the Winter and Summer national meetings. In addition the subcommittee will serve as a focus for strategic discussions of the changing needs of the physics community as it strives to understand, and respond to, the pedagogical intersection of physics and the life sciences.

The IPLS community will remain active in promoting discourse on transforming IPLS courses at AAPT and APS meetings and at other gatherings. For example, the meeting of the National Society of Black Physicists in February 2015 hosted an IPLS session. The group that organized the March 2014 IPLS Conference anticipates organizing another IPLS Conference within three or four years.

References cited in the report

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S. A. Ambrose, M. W. Bridges, M. C. Lovett, M. DiPietro, and M. K. Norman (2010). *How learning works: Seven research-based principles for smart teaching* (San Francisco: Jossey-Bass).

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A. P. French and E. L. Jossem (1976). "Teaching physics for related sciences and professions,"*Am. J. Phys.* **44**, 1149–1159.

K. L. Hall (2013). "Examining the Effects of Students' Classroom Expectations on Undergraduate Biology Course Reform," PhD Dissertation, College of Education, University of Maryland.

A. Lindow, E. Carbone, and D. J. Wagner (2013). "Similar density questions with very different results," in *PERC Proceedings 2013,* pages 221-224. (New York, AIP Press).

D.C. Meredith and E. F. Redish (2013). "Reinventing physics for life science majors," *Phys. Today* **66**, 38.

Appendix A

This section provides a detailed listing of many resources that may be of value to IPLS reformers. All of the urls were checked in early April 2015. A continuously updated version of this resource section will be posted on http://www.compadre.org/ipls/.

A. Policy documents from biology and medical professional societies

- *Bio2010: Transforming Undergraduate Education for Future Research Biologists.* National Academies report on improving the undergraduate education of biology majors, particularly grad school bound majors. (2003) http://www.nap.edu/catalog/10497/bio2010-transforming-undergraduate-education-for-future-research-biologists.
- *Scientific Foundations for Future Physicians*. AAMC/HHMI report on improving the science education of future physicians, both in undergraduate programs and in medical school. (2009) https://www.aamc.org/download/271072/data/scientificfoundationsforfuturephysicians.pdf.
- *Vision and Change in Undergraduate Biology Education: A Call to Action.* AAAS sponsored strategic plan to revamp undergraduate education in biology. (2010/11) http://visionandchange.org/.
- PULSE: The Partnership for Undergraduate Life Sciences Education is an on-line community dedicated to implementing the recommendations for *Vision and Change*. http://www.pulsecommunity.org/.

B. MCAT Resources

- *Summary of the 2009 MR5 Science Content Survey of Undergraduate Institutions.* The results of a survey that ranks the importance in medical school of topics from undergraduate science. The results of the survey were used as a guide for topic coverage on the MCAT. https://www.aamc.org/download/253684/data/aamcmr5ugnsreport.pdf.
- R. C. Hilborn, "Physics and the revised Medical College Admission Test," *Am. J. Phys*. **82**, 428 (2014).
- *What's on the MCAT2015 Exam?* This document describes the new MCAT; provides specific physics topics and an overview of critical thinking skills that are tested. https://www.aamc.org/students/services/343550/mcat2015.html.

C. Resource Letters from the *American Journal of Physics*

Resource letters are annotated bibliographies of journal articles, conference proceedings, review articles, and books.

1. On biology and medical physics:

"Resource Letter PB-1: Physics and Biology," D. James Baker, Jr., *Am. J. Phys*. **34**, 83 (1966).

"Resource Letter BE-1: Biomedical Engineering," Curtis C. Johnson, *Am. J. Phys*. **39**, 1423 (1971).

"Resource Letter TPB-1: Theoretical Physics and Biology," N. MacDonald, *Am. J. Phys*. **42**, 717 (1974).

"Resource Letter MP-1: Medical Physics," Russell K. Hobbie, *Am. J. Phys.* **53**, 822 (1985).

"Resource Letter PS-1: Physics of Sports," Cliff Frohlich, *Am. J. Phys.* **54**, 590 (1986).

"Resource Letter PPPP-1: Physical Principles of Physiological Phenomena," Bernard Hoop, *Am. J. Phys.* **55**, 204 (1987).

"Resource Letter MI-1: Medical Imaging," Stephen J. Riederer, Am. J. Phys. **60**, 682 (1992).

"Resource Letter BELFEF-1: Biological Effects of Low-Frequency Electromagnetic Fields," David Hafemeister, *Am. J. Phys.* **64**, 974 (1996).

"Resource Letter EIRLD-1: Effects of Ionizing Radiation at Low Doses," Richard Wilson, *Am. J. Phys.* **67**, 372 (1999).

"Resource Letter RA-1: Risk Analysis," Richard Wilson, Am. J. Phys. **70**, 475 (2002).

"Resource Letter PFBi-1: Physical frontiers in biology," Eugenie Vorburger Mielczarek, *Am. J. Phys.* **74**, 375 (2006).

"Resource Letter PMB-1: The Physics of Biomolecular Machines," Debashish Chowdhury, *Am. J. Phys*. **77**, 583 (2009).

"Resource Letter MPRT-1: Medical Physics in Radiation Therapy," Steven T. Ratliff, *Am. J. Phys.* **77**, 774 (2009).

"Resource Letter MP-2: Medical Physics," Russell K. Hobbie and Bradley J. Roth, *Am. J. Phys.* **77**, 967 (2009).

"Resource Letter PS-2: Physics of Sports," Cliff Frohlich, *Am. J. Phys.* **79**, 565 (2011).

"Resource Letter BSSMF-1: Biological Sensing of Static Magnetic Fields," Leonard Finegold, *Am. J. Phys.* **80**, 851 (2012).

"Resource Letter EIRLD-2: Effects of Ionizing Radiation at Low Doses," Richard Wilson, *Am. J. Phys.* **80**, 274 (2012).

2. Physics topics related to life science:

"Resource Letter: CC-1: Controlling chaos," Daniel J. Gauthier, *Am. J. Phys.* **71**, 750 (2003).

"Resource Letter: LBOT-1: Laser-based optical tweezers," Matthew J. Lang and Steven M. Block, *Am. J. Phys.* **71**, 201 (2003).

"Resource Letter CS–1: Complex Systems," M. E. J. Newman, *Am. J. Phys.* **79**, 800 (2011).

"Resource Letter TTSM-1: Teaching Thermodynamics and Statistical Mechanics in Introductory Physics, Chemistry, and Biology," Benjamin W. Dreyfus et al, *Am. J. Phys.* **83**, 5 (2015).

D. IPLS-themed journal issues

- CBE Life Science Education, Summer 2013 Issue, *Special Issue Integrating Physics and Biology Education*; Eric Brewe, Nancy J. Pelaez, and Todd J. Cooke, editors; http://www.lifescied.org/content/12/2.toc.
- *American Journal of Physics*, May 2014 Issue, *Research and Education at the Crossroads of Biology and Physics*, Mel Sabella and Matthew Lang, editors. The issue is available as an ePub at http://iweb.aapt.org/iweb/Purchase/ProductDetail.aspx?Product_code=EPUB-AJPTHEME.
- APS Forum on Education Newsletter, Fall 2014, Beth Lindsay, editor; http://www.aps.org/units/fed/newsletters/fall2014/.

E. Comprehensive IPLS archives

- **IPLS Conference** – The website for the March 2014 conference discussed in this report. The website houses plenary talks, posters, and syllabi contributed by participants. http://www.compadre.org/IPLS/.
- **IPLS Wiki** – started after the 2009 IPLS conference at George Washington University. http://ipls.wiki.daymuse.com/w/Main_Page.
- **Pre-health Collection** – A pedagogical archive maintained by the Association of American Medical Colleges that houses a growing set of materials including course packets, videos and curricular resources tied to MCAT preparation. https://www.mededportal.org/icollaborative/about/initiatives/prehealth/.
- **NEXUS (National Experiment in Undergraduate Science Education)** – Joint project from the physics and biology education research groups at the University of Maryland with a comprehensive set of research papers, a Wiki-based text, and labs. http://umdberg.pbworks.com/w/page/44091483/Project%20NEXUS%20UMCP.

F. ComPADRE

ComPADRE (the physics and astronomy digital library) hosts IPLS content (research papers, curricular packages). A project is underway to make a cohesive portal to allow easier access to the material. http://www.compadre.org and http://www.compadre.org/per/.

G. Articles about reforming the IPLS course

There has been an upsurge of articles seeking to develop a new vision of the IPLS course. The following list is representative, but far from exhaustive.

- E. F. Redish and D. Hammer, "Reinventing college physics for biologists: Explicating an epistemological curriculum," *Am. J. Phys*. **77**, 629 (2009).
- C. H. Crouch, R. Hilborn, S. A. Kane, T. McKay, and M. Reeves, "Physics for future physicians and life scientists: A moment of opportunity," *APS News* **19**, 3, Back Page, (2010).
- J. Watkins, J. E. Coffey, E. F. Redish, and T. J. Cooke, "Disciplinary authenticity: Enriching the reform of introductory physics courses for life science students," *Phys. Rev. ST Phys. Ed. Res*. **8**, 010112-1-17 (2012).
- D. C. Meredith and J. A. Bolker, "Rounding off the cow: Challenges and successes in an interdisciplinary physics course for life science students," *Am. J. Phys.* **80**, 913 (2012).
- D. C. Meredith and E. F. Redish, "Reinventing physics for life science majors," *Phys. Today* **66**, 38 (2013).
- E. F. Redish et al, "NEXUS/Physics: An interdisciplinary repurposing of physics for biologists," *Am. J. Phys*. **82**, 368 (2014).
- K. Moore, J. Giannini and W. Losert, "Toward better physics labs for future biologists," *Am. J. Phys.* **82**, 387 (2014).
- C. Crouch and K. Heller, "Introductory physics in biological context: An approach to improve introductory physics for life science students," *Am. J. Phys.* **82**, 378 (2014).

H. Introductory physics textbooks

There are a number of introductory textbooks that utilize a traditional physics content development but are beginning to incorporate more life-science examples. This list provides examples of introductory texts that have significant life science content. Again, this list is representative rather than comprehensive. For readers interested in what textbooks other faculty are currently using, we suggest looking at the IPLS syllabi on the ComPADRE website (http://www.compadre.org/ipls/).

- M. M. Sternheim and J. W. Kane, *General Physics,* 2nd ed. (Wiley, 1991). Includes many applications in the life sciences.
- George B. Benedek and Felix M.H. Villars, *Physics with Illustrative Examples from Medicine and Biology* (Springer, 2000). A three-volume series written for a one-year introductory course providing a sophisticated treatment of biological phenomena.
- Tim McKay's calculus-based IPLS course packet is evolving into a textbook to be published by Pearson with co-author Catherine Crouch. http://www.umich.edu/~tamckay/IPLS.
- NEXUS Wiki-based textbook for the University of Maryland's Physics 131 http://umdberg.pbworks.com/w/page/90716129/Working%20content%20I%20(2015).
- For the University of Maryland's Physics 132 http://umdberg.pbworks.com/w/page/72420260/Working%20content%20II%20(2013).

I. Books suitable as supplements for standard introductory physics courses

- John R. Cameron, James G. Skofronick, and Roderick Grant, *Physics of the Body* (Medical Physics Pub Corp, 1999).
- A. Tuszynski and J. M. Dixon, *Biomedical Applications for Introductory Physics* (Wiley, 2001).
- Paul Davidovits, *Physics in Biology and Medicine* (Academic Press, 2012).

J. Textbooks for physics courses beyond the introductory level

- Russell K. Hobbie and Bradley J. Roth, *Intermediate Physics for Medicine and Biology,* (Springer, 2007). This book is intended for use in a course to follow a standard one-year intro physics course.
- Suzanne Amador Kane, *Introduction to Physics in Modern Medicine* (CRC Press, 2009).
- William Bialek, *Biophysics: Searching for Principles* (Princeton University Press, 2012). Aimed at graduate students in physics with an interest in biophysics.

K. Biology and biophysics textbooks with a physics orientation

There are a number of biology/biophysics texts with a significant amount of physics content. Below is a sample of what is available.

- Mark W. Denny, *Air and Water: The Biology and Physics of Life's Media* (Princeton University Press, 1995).
- Robert Plonsey and Roger Barr, *Bioelectricity: A Quantitative Approach,* 3rd ed. (Springer, 2007). An introduction to electrophysiology aimed at engineering students.
- Sarah Otto and Troy Day, *A Biologist's Guide to Mathematical Modeling in Ecology and Evolution* (Princeton University Press, 2007).
- Irving P. Herman, *Physics of the Human Body* (Springer, 2008).
- Michael Goitein, *Radiation Oncology: A Physicist's-Eye View* (Springer, 2008).
- Thomas M. Nordlund, *Quantitative Understanding of Biosystems: An Introduction to Biophysics* (CRC Press, 2011).
- Jay Nadeau, *Introduction to Experimental Biophysics: Biological Methods for Physical Scientists* (CRC Press, 2011).
- Roland Ennos, *Solid Biomechanics* (Princeton University Press, 2011). Biomaterials, stress, strain.
- Sonke Johnsen, *The Optics of Life: A Biologist's Guide to Light in Nature* (Princeton University Press, 2012).
- Rob Phillips, Jané Kondev, Julie Theriot, and Hernan Garcia, *Physical Biology of the Cell* (Garland Science, 2012).
- Philip Nelson, *Biological Physics: Energy, Information and Life* (W.H. Freeman, 2013).
- Steven Vogel, *Comparative Biomechanics: Life's Physical World* (Princeton University Press, 2013).
- Philip Nelson, *Physical Models of Living Systems* (W.H. Freeman, 2015). This upper-level undergraduate book contains a number of physical models that could be adapted for use in IPLS courses.

L. Semi-popular biology books with significant physics content

- Steven Vogel, *Life in Moving Fluids: The Physical Biology of Flow* (Princeton University Press, 1983).
- Knut Schmidt-Nielsen, *Scaling: Why Is Animal Size So Important* (Cambridge University Press, 1984).

- Steven Vogel, *Life's Devices: The Physical World of Animals and Plants* (Princeton University Press, 1988).
- L. Glass and M. C. Mackey, *From Clocks to Chaos, The Rhythms of Life* (Princeton University Press, 1988). Nonlinearity with biological relevance.
- Steven Vogel, *Vital Circuits: On Pumps, Pipes, and the Workings of the Circulatory Systems* (Oxford University Press, 1993).
- Howard C. Berg, *Random Walks in Biology* (Princeton University Press, 1993).
- Steven Vogel, *Cats Paws and Catapults: Mechanical Worlds of Nature and People* (W.W. Norton, 2000).
- Steven Vogel, *Prime Mover: A Natural History of Muscle* (W. W. Norton, 2002).

M. Curricular resources available online

- The Bionumbers website contains a wealth of quantitative information about living systems. http://bionumbers.hms.harvard.edu.
- The Humanized Physics Project has activities and labs for IPLS, http://physics.doane.edu/hpp/.
- University of Maryland, http://mathbench.umd.edu/, designed to help biology students get a conceptual understanding of mathematics used frequently in biology. It is organized mostly by biology applications.
- American Association of Medical Colleges, iCollaborative. https://www.mededportal.org/icollaborative/about/initiatives/pre-health/, a searchable repository of curriculum for pre-professional students.
- Benedictine University, http://circle4.com/biophysics/modules/, teaching materials in the form of a self-contained series of self-study guides (modules) that focus on stochastic phenomena such as diffusion, drug elimination and osmosis.
- BEN Portal, the digital library for bioscience education houses over 18,000 reviewed resources. http://www.biosciednet.org/portal/.
- The Life Science Teaching Resource Community houses educational resources for all levels of students. They currently have over 6700 peer reviewed resources. http://www.lifescitrc.org/.
- Kansas State University, http://web.phys.ksu.edu/mmmm/student/l labs related to medical devices (MRI, PET, Vision, Wave front aberrometry, locating bullets). Includes instructor resources.
- Mercy College, https://mercy.digication.com/biomechanics_activities_/Home//, human biomechanics activities and experiments.
- Portland State University, http://web.pdx.edu/~ralfw/biomedical-projects.html, Labs related to medical devices (CT, EKG, Pulse-ox, BIA, and more....). Includes instructor resources.
- Rockhurst University, https://www.mededportal.org/icollaborative/about/initiatives/prehealth/ Student activities currently available: Fiber Optics in Medicine Module and Investigating the Respiratory System. Coming soon: Fiber Optics in Medicine and Investigating the Cardiovascular System. These are for a Physics of Medicine course, after a first physics course, and take about 3 weeks to do for each module. Email Nancy Donaldson (nancy.donaldson@Rockhurst.edu) for instructor guides.
- Swarthmore College, http://materials.physics.swarthmore.edu/iplsmaterials/ resources for a second semester IPLS course (focus on optics and electromagnetism). Includes labs, clicker questions and homework.
- University of Maryland, http://nexusphysics.umd.edu/. Need to request access online. This is a complete set of resources for their IPLS class (on-line text, clicker questions, lab, homework, instructor guides, related publications) for both semesters. Includes instructor resources.
- University of Massachusetts Amherst, http://people.umass.edu/rossj/Teaching.html. This describes a full course on building a microscope.
- University of Michigan, http://www.umich.edu/~tamckay/IPLS. Includes practice exams, lecture slides, and course pack for a two-semester calculus-based course.
- University of New England, http://faculty.une.edu/cas/jvesenka/scholarship/index.htm. Buoyancy, Bernoulli, ideal gas lab modeling instruction labs and assessments.
- University of New Hampshire, http://ipls.unh.edu. First semester materials (annotated bibliographies, lecture slides, questions, with an emphasis on fluids, materials (e.g., stress/strain), and trigonometry). Includes instructor guides.
- http://simbio.com/products-college/OsmoBeaker has simulations on osmosis, diffusion and action potentials. There is a free demo, but student versions do have a charge. The research related to this is available at E. Meir, J. Perry, D. Stal, S. Maruca, and E. Klopfer, "How Effective Are Simulated Molecular-level Experiments for Teaching Diffusion and Osmosis?" *Cell Biol. Educ*. **4** (3) 235-248 (2005).

N. Resources on interactive-engagement pedagogy

- John D. Bransford, Ann L. Brown, and Rodney R. Cocking, (eds) *How People Learn: Brain, Mind, Experience and School* (National Academies Press, 2000).
- R. D. Knight, *Five Easy Lessons* (Addison Wesley Longman, San Francisco, CA, 2003).
- E. F. Redish, *Teaching Physics with the Physics Suite* (Wiley, New York, 2003).
- S. A. Ambrose, M. W. Bridges, M. C. Lovett, M. DiPietro, and M. K. Norman, *How Learning Works: Seven research-based principles for smart teaching* (Jossey-Bass, San Francisco, 2010).
- S. R. Singer, N. R. Nielsen, and H. A. Schweingruber, eds. *Discipline-Based Education Research: Understanding and Improving Learning in Undergraduate Science and Engineering* (The National Academies Press, Washington, DC. 2012).
- D. E. Meltzer and R. K. Thornton, "Resource Letter ALIP–1: Active-Learning Instruction in Physics," *Am. J. Phys*. **80**, 478 (2012).
- Linda Korber and Board on Science Education, *Reaching Students: What Research Says About Effective Instruction in Undergraduate Science and Engineering* (National Research Council, Washington, DC, 2015).
- PhysPort – This website provides a searchable and annotated database of tested physics pedagogies for a wide variety of physics courses. https://www.physport.org/.
- Carl Wieman Science Education Initiative website with many resources on reformed pedagogy in college science courses. http://www.cwsei.ubc.ca/index.html.
- Science Education Resources Center, http://serc.carleton.edu/NAGTWorkshops/index.html. Wide ranging resources for undergraduate STEM education, with an emphasis on the geosciences.
- MERLOT II, http://physics.merlot.org/. Another online repository of curricular materials.
- PULSE Community, http://www.pulsecommunity.org/. The Partnership for Undergraduate Life Science Education–a growing online community of life scientists and societies focused on implementing the recommendations of the *Vision and Change* document.

O. Resources on course reform

- Grant Wiggins and Jay McTighe, *Understanding by Design,* 2nd ed. (Association for Supervision and Curriculum Development, 2005). A practical guide to designing a course by starting with learning goals and objectives.
- http://www.cwsei.ubc.ca/resources/files/CourseTransformationGuide_CWSEI_CU-SEI.pdf. A guide to course transformation at the college and university level.
- S. V. Chasteen, K. K. Perkins, P. D. Beale, S. J. Pollock, and C. E Wieman, "A Thoughtful Approach to Instruction: Course Transformation for the Rest of Us," *Journ. Coll. Sci. Teach*. **40**, 76 (2011).
- The Partnership for Undergraduate Life Science Education (PULSE) has produced a rubric for gauging departmental and course reform in the life sciences but the general principles apply to physics as well. PULSE Vision & Change Rubrics v1.0.pdf at http://www.pulsecommunity.org/.

P. Resources for institutional change

- Catherine Fry, ed. *Achieving Systemic Change: A Sourcebook for Advancing and Funding Undergraduate STEM Education* (AACU, 2014).http://www.aacu.org/sites/default/files/files/publications/E-PKALSourcebook.pdf.
- Carl Wieman Science Education Initiative, http://www.cwsei.ubc.ca/.

Q. Resources for assessment of student learning

- K. M Fisher, K. S. Williams, and J. E Lineback, "Osmosis and Diffusion Conceptual Assessment," *CBE Life Sci. Educ.* **10** (4) 418-429 (2011). The assessment itself is available as supplemental material.
- MBEX (Maryland Biology Expectations Survey) is available at http://www.physics.umd.edu/perg/dissertations/Hall/ or by contacting Kristi Hall at khall@umd.edu.
- A survey on fluids statics is currently under development. You can obtain a copy by emailing DJ Wagner at DJWagner@gcc.edu. The results of the current version are used to gain information that will help focus the final assessment. Details on survey development are in [Lindow, Carbone and Wagner 2013].

Appendix B

This section provides a condensed listing of the conclusions and recommendations articulated by the conference participants. It may serve as a useful "check list" for those working on enhancing IPLS courses.

A. Recommendations for faculty, departments, colleges, and universities

Find an appropriate balance between the physics core concepts (which give a coherent story line and teach valuable thinking skills) and life science applications.

- Construct a coherent story line that comes from physics, focusing on key principles such as Newton's laws, conservation laws, and fundamental interactions.
- Help students see that physics is essential for understanding living systems because it both constrains and enables how organisms get their work done at both the molecular and organismal levels.
- Include authentic life science applications so that the students can see how to apply physics principles to messy, complex life science situations; in practice, they cannot easily make these connections on their own.
- Help students develop physics thinking tools:
  - – Connecting meaning and mathematics
  - – Using multiple representations of physical situations
  - – Problem solving skills (both qualitative and quantitative)
  - – Developing, using, and evaluating quantitative models
  - – Reasoning from a few fundamental, quantitative principles
  - – Looking for coherence and mechanisms
- Offer a course that is as rigorous and engaging as the course for engineers and physical scientists, but in ways appropriate to the life sciences.
- Physicists should not see IPLS course reform as giving control of the curriculum to the life scientists, but they should listen to the needs of the departments and graduate programs that are require an IPLS course for their students.

Work closely with the life scientists on your campus.

- Include biologists at all levels: professors, lab supervisors, graduate students (as TAs), and undergraduates (as Learning Assistants). Advanced life science undergraduates can be a relatively inexpensive source of ongoing support. (Check out "Learning Assistants" at http://serc.carleton.edu/sp/library/learning_assistants/index.html and Peer Led Team Learning at https://sites.google.com/site/quickpltl/ as ways to support and make good use of undergraduates.)
- You will need the life scientists' help to
  - – Set learning outcomes that make sense for IPLS students.
  - – Have students value physics by explicitly using it in their life science classes.
  - – Value the IPLS course in advising conversations. This is not a course "to get out of the way," but a course that will make the students develop a deeper understanding of living systems.
  - – Require physics to be taken early in students' academic careers so it can be a prerequisite for higher-level life science courses.
  - – Understand where life science students will struggle with the physics perspective.
  - – Create biologically authentic applications.
  - – Share equipment (e.g. microscopes).

Revisit topic coverage with life science applications in mind.

- There are many topics of interest to many biologists that are not covered at all or not deeply enough in most introductory physics courses. Include life scientists in this conversation. Keep in mind that different life science sub-disciplines need different physics topics. Adding new topics will necessarily mean dropping some standard physics topics.
- Key topics you might consider including in an IPLS course are the following:
  - – Transport processes: diffusion, osmosis, convection, conduction
  - – Electrical currents across cell membranes
  - – Fluid statics and dynamics
  - – Feedback and control
  - – Waves – sound and light
  - – Nuclear radioactivity
  - – Thermal physics from a statistical point of view with a focus on molecular processes (entropy, enthalpy)
  - – Human biomechanics

- Standard topics you might consider leaving out or reducing coverage:
  - 2D and 3D kinematics,
  - Angular kinematics and dynamics,
  - Planetary orbits and universal gravitation,
  - Heat engines.

Use interactive engagement pedagogy to improve learning outcomes.

- Curricular materials should be designed with effective, research-validated pedagogy.
- The life science reports listed in Appendix A advocate for inquiry-based peer-learning environments.
- There are many research-based strategies for using interactive engagement pedagogy even in large classes.
- Flipped classrooms or SCALE-UP classrooms are valuable, but may not be possible for all due to local resource limitations.
- Work to reshape students' beliefs about learning (e.g. learning is memorizing) because these beliefs affect learning in significant ways.
- See the section on pedagogy resources in Appendix A for more detailed information.

Focus on teaching quantitative and representation skills, which are just as important as physics content.

- Life science students are required to take physics, in part, to learn how to use mathematics to model living systems. Instructors need to be aware of what skills their students have and the mathematics expectations of the life science faculty. The following skills are seen as essential for many IPLS students:
  - Connecting meaning and mathematics; students should be able to infer consequences from equations and not see equations as simply a tool to do a calculation.
  - Graphing and inferring information from graphs.
  - Using scaling arguments to see why size matters.
  - Using order of magnitude estimates.
  - Distinguishing a quantity from its rate of change.
  - Using proportional and statistical reasoning.
  - Developing, using, and evaluating quantitative models of biological systems. This includes being aware of assumptions and knowing when the assumptions are reasonable.
  - Using multiple representations: sketches, plots, equations, words, vectors.
  - Using computational tools such as Excel or Wolfram Alpha to extend the types of systems studied.
  - Using exponential and logarithmic functions, including being able to connect parameters to measured quantities.
  - Thinking and reasoning about stochastic processes such as diffusion and radioactive decay.

Make reform manageable by starting small and supporting reformers.

- Make incremental changes over several years in order to keep from being overwhelmed.
- Reforming a few instructional labs might be an easy place to start.
- Chairs and deans can support course reform with money for laboratory equipment, release time, summer support, additional graduate teaching assistants or undergraduate learning assistants.
- Co-teaching of the IPLS course can spread the load of making reforms, allow for on-going conversations and brainstorming about the course, and make department-wide buy-in more likely.
- If adjuncts teach the IPLS course, special care needs to be taken to assure that changes that they make have departmental buy-in. Also adjuncts need to be supported with professional development opportunities or financial support if they are expected to make major changes in the course.
- Interdepartmental groups (e.g. REBUILD at University of Michigan https://rebuild.lsa.umich.edu/) can support significant reform of introductory STEM courses across departments.

Work closely with other members of your department to ensure sustained reform.

- The course reforms can only be sustained if there is wide buy-in from the department about course learning outcomes and topics to be covered.
- Assessing student outcomes and using those results to inform further changes in the course will facilitate ongoing improvements.

Be aware that the IPLS course is very different at different institutions.

- There cannot be a one-size-fits-all IPLS course, since student populations vary widely along the following dimensions:
  - Mathematics background (calculus or algebra)
  - Chemistry and biology background
  - Career aspirations (physician, veterinarian, physical therapist, nutritionist, research molecular biologist, etc.)
  - Majors besides life sciences majors in the course
  - The number of transfer students or the number likely transfer to other types of IPLS courses
  - Size of course

B. Critical Needs for Ongoing IPLS Curriculum Reform

Create an online repository of materials (curricular materials, learning goals, assessments). To be useful, this repository must :

- Be searchable on different tags: objectives, topics, life science applications, pedagogical approach, pre-requisites, and so on.
- Have a rating system with feedback indicating if the material was useful and why, and the conditions under which the materials were deployed.
- Host materials that are modular so instructors can pick and choose what they need.
- Have materials that are modifiable for local needs.
- Include comprehensive lists of textbooks and other resources with user reviews.
- Include details of and rationale for model curricula for particular audiences.

Facilitate ongoing conversation about issues facing IPLS instructors.

- Create an active and organized online community with appropriate web infrastructure to foster ongoing discussion of IPLS issues.
- What topics are useful for what kinds of life science students?
- Could there be a few standardized "plug-and-play" IPLS courses or simply recommendations with rationales so that decisions can be made locally?
- How do we best help students who transfer into or out of reformed IPLS courses?
- What is working and what is not in various types of IPLS courses?
- What are some solutions for the various flavors of this course? (e.g. algebra versus calculus; small versus large institutions; pre-meds versus research life scientists)?
- How do we discuss possible reform efforts with our administrations?

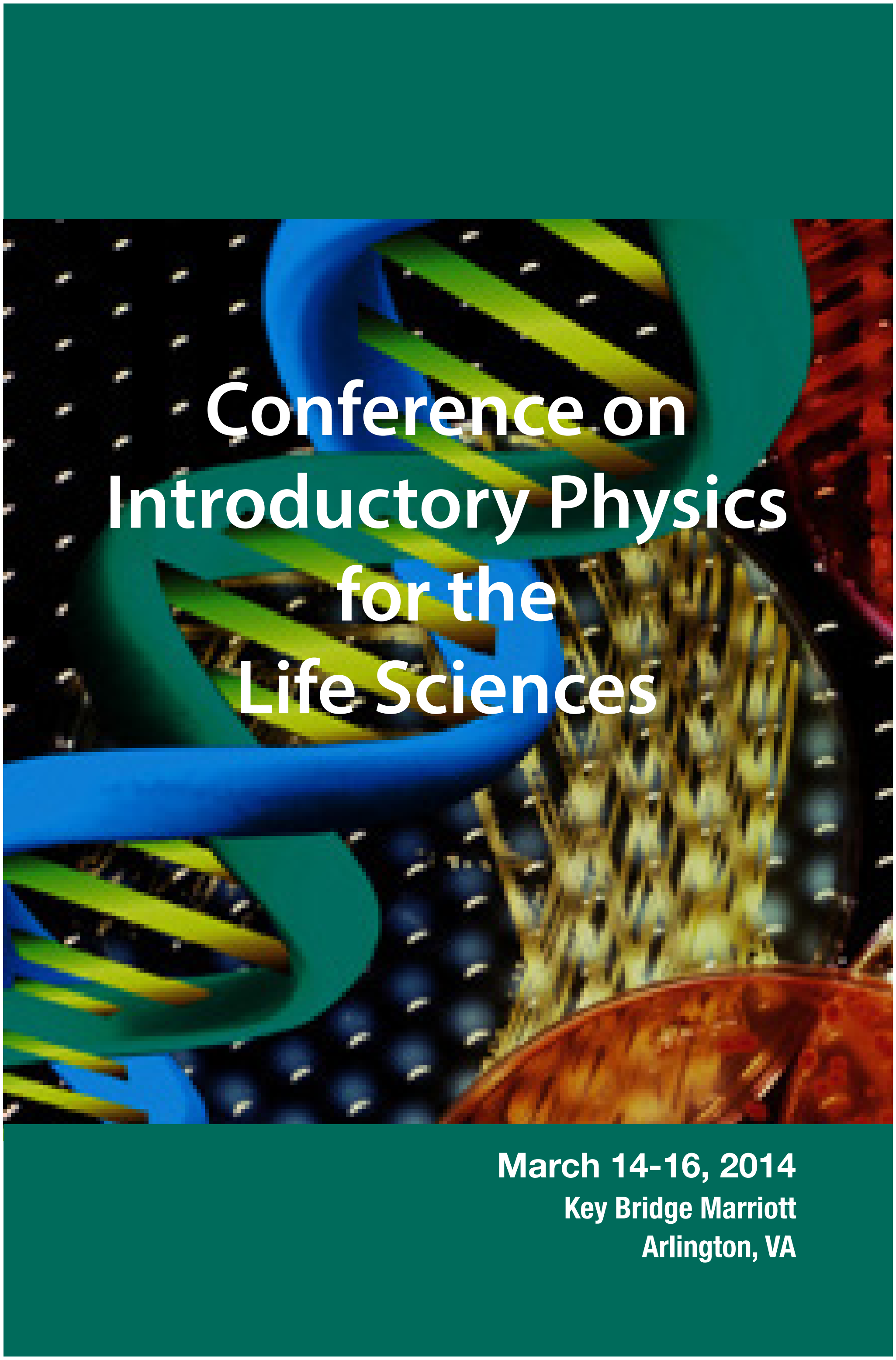
Design assessments that test key concepts for IPLS courses.

- Existing concept inventories in physics, such as the Force Concept Inventory, and similar assessments, do not assess key IPLS topics, such as chemical energy and electrical interactions in aqueous environment.
- Assessments should also align with the competency model promoted by the *Scientific Foundations for Future Physicians* and by the new MCAT.

Offer professional development for faculty members and teaching assistants new to IPLS courses.

- Offer local conferences or webinars for more easily accessed professional development.
- Offer workshops that give participants time to learn life science content, to use techniques relevant to the life sciences, and to create or modify curricular resources.
- Offer an "apprentice" program (like the Advanced Lab ALPhA program (http://www.advlab.org/) that allows physics faculty members to learn from those who have developed successful IPLS materials and labs.

Appendix C


Conference on
Introductory Physics
for the
Life Sciences
March 14-16, 2014
Key Bridge Marriott
Arlington, VA

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AAPT PHYSICS EDUCATION **American Association of Physics Teachers**

NSF **National Science Foundation**

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Friday, March 14

noon–4:00 p.m.	**Registration and Poster Set Up**
3:00–4:00 p.m.	**Reception in poster area,** Capital View Ballroom Foyer
4:00 p.m.	**Welcoming Remarks and Introductions,** Potomac Ballroom Beth Cunningham, *AAPT Executive Officer* Bob Hilborn, *AAPT Associate Executive Officer*
4:15-6:25 p.m.	**Plenary I: The View from Biology, Chemistry, and Medicine** Potomac Ballroom, Moderator: Bob Hilborn
4:15-4:45 p.m.	**A new biology education for the 21st century** Susan Rundell Singer, *Division of Undergraduate Education, National Science Foundation*
4:45-5:15 p.m.	**Developing a learning progression for understanding energy changes at the atomic–molecular level** Melanie M. Cooper and Nicole M. Becker, *Department of Chemistry, Michigan State University*
5:15–5:25 p.m.	**Short Break**
5:25-5:55 p.m.	**An overview of the new MCAT® exam** Marc Kroopnick, *Association of American Medical Colleges*
5:55- 6:25 pm	**Daunting challenges and golden opportunities for teaching physics to biology students** Todd J. Cooke, *Department of Cell Biology and Molecular Genetics, University of Maryland*
6:30–7:30 p.m.	**Dinner**, Capital Ballroom
7:30-8:30 p.m.	**Plenary II: Case Studies from the Pedagogical Interface between Biology and Physics** Potomac Ballroom, Moderator: Catherine Crouch
7:30–8:00 p.m.	**IPLS Reform: still plenty of questions** Dawn Meredith, *Department of Physics, University of New Hampshire*
8:00-8:30 p.m.	**NEXUS/Physics: an interdisciplinary repurposing of physics for life science students** Edward F. Redish, *Department of Physics, University of Maryland*
8:30-9:30 p.m.	**Posters**, Capital View Ballroom Foyer

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Saturday, March 15

8:00-9:00 a.m.	**Plenary III: Laboratories for Introductory Physics for the Life Sciences** Potomac Ballroom, Moderator: Paul Gueye
8:00-8:30 a.m.	**Overview of IPLS labs: where are we now and where should we be going?** Nancy Beverly, *Department of Physics, Mercy College*
8:30-9:00 a.m.	**Designing and implementing a sustainable laboratory as a coherent part of an IPLS course** Ken Heller, *School of Physics and Astronomy, University of Minnesota*
9:00-10:15 a.m.	**Working Groups Session I: Course Transformation and Learning Goals**
	At the end of my physics course, a biology student should be able to…. Michelle Smith, *School of Biology and Ecology, Maine Center for Research in STEM Education, University of Maine*
10:15-10:45 a.m.	**Break in Poster Area**
10:45-11:45 a.m.	**Plenary IV: Case Studies of IPLS Courses** Potomac Ballroom, Moderator: Patricia Soto
10:45-11:15 a.m.	**Reforming physics for the life sciences at the University of Michigan** Tim McKay, *Department of Physics, University of Michigan*
11:15-11:45 a.m.	**Physics of medicine – my field of dreams** Nancy L. Donaldson, *Department of Physics, Rockhurst University*
11:45-12:30 p.m.	**Working Groups II: Defining Strategies and Resources for IPLS Course Transformation**
12:30-1:30 p.m.	**Lunch**, Capital Ballroom
1:30-2:45 p.m .	**Plenary Panel I: More Views from Biology** Potomac Ballroom, Moderator: Mark Reeves

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1:30-2:30 p.m. **Panelists Presentations** (20 minutes each)

Designing circulatory systems—evolution dances but physics calls the tunes
Steve Vogel, *Department of Biology, Duke University*
Using physics to turn biological cartoons into mathematical models of cells
Jané Kondev, *Department of Physics, Brandeis University*
What is the place of physics in a coherent, engaging, and effective biology curriculum?
Mike Klymkowsky, *Molecular, Cellular, and Developmental Biology, University of Colorado-Boulder*

2:30-2:45 p.m. **Discussion**

2:45-3:15 p.m. **Break and Posters**

3:15-4:15 p.m. **Working Groups III: Take-home Ideas from Today's Presentations**

4:15-5:30 p.m. **Plenary Panel II: Mathematics and IPLS Courses**
Potomac Ballroom, Moderator: Juan Burciaga

4:15-5:15 p.m. **Panelist Presentations** (20 minutes each)

IPLS in un-IPLS courses: project-based learning in a mixed enrollment course
David Weaver, *Physics, Chandler-Gilbert Community College*
University physics for the life sciences: calculus-based introductory physics re-imagined
Simon Mochrie, *Department of Physics, Yale University*
Mathematics: transcending the sciences
Scot Gould, *W.M. Keck Science Department, Claremont McKenna, Pitzer & Scripps Colleges*

5:15-5:30 p.m. **Discussion**

5:30-6:15 p.m. **Free Time**

6:15-7:15 p.m. **Dinner**, Capital Ballroom

7:15-8:15 p.m. **Posters**, Capital View Ballroom Foyer

8:15 p.m. **Take down posters**

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	N. B. Hotel Check-out Before Noon
8:00-8:55 a.m.	**Working Groups IV: Formulating Recommendations for IPLS Courses**
9:00-10:00 a.m.	**Plenary VI: Course Transformation Revisited** Potomac Ballroom, Moderator: Eric Brewe **The intimate relationship between expertise, learning goals, pedagogy, and course transformation** Carl Wieman, *Department of Physics and Graduate School of Education, Stanford University*
10:00 -10:30 a.m.	**Refreshment Break**
10:30-11:30 a.m.	**Plenary Discussion: Reports from Breakouts** Potomac Ballroom, Moderators: Dawn Meredith and Tom O'Kuma
11:30 a.m.	**Final Remarks, Post-Conference Survey, Conference Report Development** Potomac Ballroom, Moderator: Bob Hilborn

American Association of Physics Teachers

Founded in 1930, The American Association of Physics Teachers (AAPT) is dedicated to enhancing the understanding of physics through teaching. For our members who serve physics students across the spectrum of schools, colleges, and universities, AAPT is a professional home that helps bring together knowledgeable and innovative colleagues who care deeply about physics teaching and education, and that offers valuable resources and benefits.

We serve our members through programs, publications, and networking, but also reach out to the larger community of physics and science teachers—current and future—and we look after issues of significance in science education. The national office works closely with our dedicated volunteers around the nation and beyond to promote a better understanding of physics at all levels. The association supports physics educators at all levels through our two publications, the *American Journal of Physics* and *The Physics Teacher*; NSF-funded programs including the Physics Teaching Resource Agents institutes; the digital physics library, ComPADRE (with APS and AIP); the Physics Teacher Education Coalition, PhysTEC (with APS and AIP); the Workshops for New Physics and Astronomy Faculty (with APS and AAS); two national annual meetings; and the student programs and scholarships that we administer, including the Lotze Scholarship for Future Teachers, the High School Physics Teacher Grants, the Physics Bowl, and the U.S. Physics Olympiad.

Beth Cunningham
Executive Officer

American Association of Physics Teachers
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Appendix D

IPLS Pre-Conference Survey Report

Prepared by Stephanie Chasteen, sciencegeekgirl enterprises

Date: February 28, 2014

Table of Contents

Executive Summary

Overall, the conference attendees represent an unusually open, enthusiastic, and thoughtful group of faculty. They are aware of the issues and challenges facing IPLS courses, and recognize many systemic issues (including their own lack of professional development) relevant to transformation of these courses. These faculty use PER-driven and interactive instructional techniques more than the average physics faculty. The motivation and experience of this group provides a rather exciting opportunity to make substantial progress towards the goals of the conference—namely, to articulate some of the needs of IPLS courses, and identify and highlight existing resources. However, because the conference attendees do represent an exemplary group, care should be taken to address the challenges that they may face in selling ideas from the conference to their more traditional colleagues at their home institution. Providing mechanisms for ongoing community and communication among conference attendees will also help to support them in this continuing work. Below are some of the main findings from the pre-conference survey.

About the participants. Meeting participants are primarily faculty and instructors in physics departments who have either taught, or are planning to teach, an IPLS course (though not every institution has an IPLS course). About half have taught an IPLS course in the past. Respondents are attending the conference to get ideas and guidance, including resources, curricula, topics, and approaches to IPLS courses.

Their interest in IPLS course transformation

- Many respondents recognize a need to transform courses, and most indicate that they have transformed the IPLS course in the past, or are currently or plan to transform the course.
- Several challenges to transforming IPLS courses are cited, mostly time and resources, in addition to lack of faculty expertise, or buy-in from faculty or administration.
- Some (14%) indicate that they have met resistance to making changes.

About IPLS courses in their department

- **Textbook.** There is no one agreed-upon text, but the most common are *College Physics* (by Knight, Jones and Field) and *Physics* (Giancoli).
- **Pedagogy.** A surprising number are using interactive techniques–including group work (75%), clickers (67%), and tutorials 59%).
- **Mathematical pre-requisites.** Most IPLS courses require algebra and trigonometry, and most do not include calculus.
- **Modification of topics, problem sets, and labs.** Most indicate that, compared to the traditional course aimed at physics majors, the course is only adjusted in a minor way. Most indicate that they offer a course that is “palatable” to biology students, rather than “highly relevant.”
- **Physics content.** Physical topics covered mirror traditional physics topics quite closely, and there is fairly broad consensus across participants.
- **Biological content.** Biological topics included are much more diverse, with only small fractions of participants indicating that any one topic is covered (with the exception of vision). Comments suggest these topics are only “covered” as examples or on problem sets.
- **Departmental climate.** Most participants said that their departments were not aware of the reports calling for reform of IPLS courses (50%), but a significant fraction were aware and had a positive reaction (35%). A surprising number of participants are engaged in departmentally led efforts to transform IPLS courses. Respondents were not asked about the overall climate towards IPLS courses in their department, but several respondents indicated concern about buy-in or motivation to change these courses among colleagues.

About IPLS courses that they themselves teach

- **Instructors use techniques to make the content relevant for life sciences students**, primarily using examples and problems from biology and health, and connecting material to the real world, but some also provide more interactive techniques, or include more relevant topical areas.
- **Instructors face many challenges in teaching IPLS courses,** including low mathematical preparation of students, uncertainty about which topics should be kept and which should be dropped, and the fact that their course serves an audience that includes, but is not limited to, biology students. Lack of instructional resources and faculty buy-in are also cited.
- **Instructors cite many challenges that they would face in making changes to their IPLS course**, such as lack of time, a good textbook, faculty buy-in, and faculty professional development for implementing such changes.

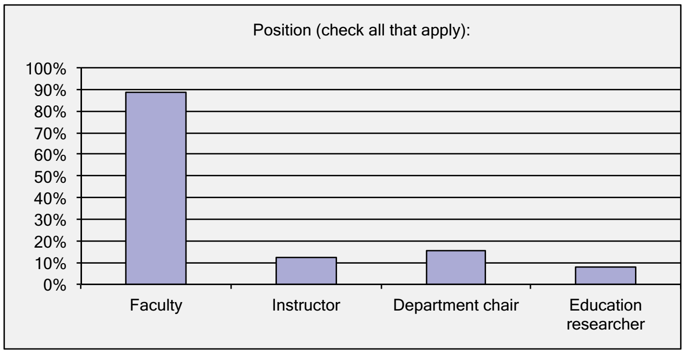
About this Report

A pre-conference survey was sent to the 161 registered attendees of the conference. Participants were offered a chance of one of three $50 Amazon gift certificates for their responses. As of the survey analysis on February 28th, a total of 102 responses had been received for a response rate of 63%, which is acceptably high.

The survey addressed the participants’ background, interest in IPLS courses, and asked about the content and approach of IPLS courses at their institution.

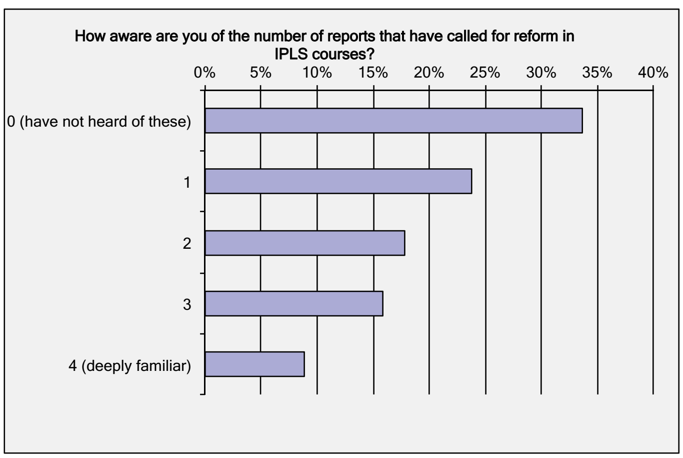
About the Respondents

The vast majority of respondents are members of **physics departments** (97.8%), with 15 attendees being members of other departments (only six are members of a department with a biological focus). **The majority are faculty,** with a smaller percentage in other positions as shown in the graph below.



About half of meeting participants have taught an IPLS course in the past, with the rest planning to teach an IPLS course (30%), or involved in education research or curriculum development (15%).

Most meeting attendees are not very familiar with the reports calling for change in IPLS courses (e.g., Bio 2010, Vision and Change, Scientific Foundations for Future Physicians).

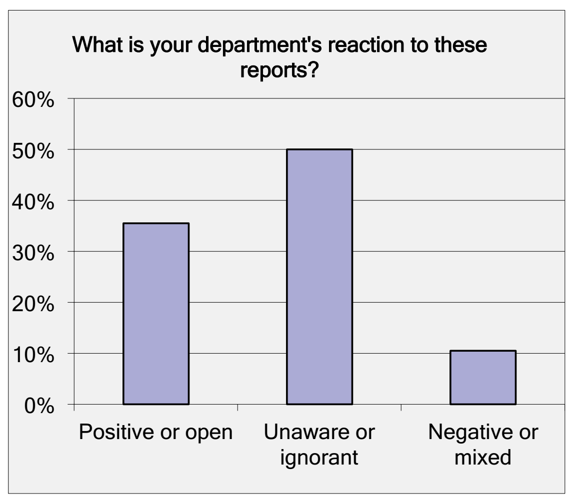


Participant reactions to these reports were positive (open ended question, N=77 respondents). The types of answers given were:

- Strongly in favor of the conclusions, and positive response (the majority of answers).
- Reasonable proposals.
- Good first step, providing motivation and justification to change, but impact is uncertain:
  - –Resistance in some departments.
  - –Difficult to find time to incorporate changes, faculty are busy.
  - –Hard to know how to implement changes.

Departmental reactions to these reports was often indifferent or ignorant, but a sizeable fraction were positive or open to these recommendations. Open-ended responses (N=76) were coded by the general climate, with results shown below. Sample responses include:

- My department is very open-minded and motivated to rethink the way we teach physics to life science majors.
- They are keen to listen and trying to make the right changes.
- We read them and are thinking about them.
- They are not aware.
- I think we range from not sold, to skeptical.
- Generally unfavorable, as it would require a significant change to the rote curriculum/laboratory process.



Participants' Interest in the Conference

Participants are coming to the conference primarily for ideas and guidance to use in their IPLS courses, including what works and what doesn't. Many seem to think that there is an existing body of knowledge that they will be able to glean from the conference. Responses (N=90) are summarized below, in rough order of frequency of mention.

- Find out what others are doing to transform IPLS courses; what works and what doesn't.
- How to think about the topics, examples, and content that should be included in IPLS courses.
- Exchange ideas with colleagues, an ongoing community.
- Challenges to consider, pitfalls, how to deal with push-back from colleagues.
- Resources, curricula, labs, ideas, approaches, teaching techniques, best practices, for IPLS courses.
- How to deal with diverse mathematical preparation.
- Identifying student needs in these courses.
- How to motivate students to learn the material.
- How to balance the needs of a diverse student population (i.e., not just biology majors take these courses).

Participants give a few suggestions for the conference organizers:

- Provide access to conference materials (PPT presentations, handouts).
- Provide access to curriculum materials, topic lists, resources, and classroom-ready materials via download or flash drive.
- Allow plenty of time for unstructured discussion and debate as well as presentation of information.
- Provide ongoing structure (e.g., online repository) to help continue with course planning.

About IPLS Courses at Institution

Most respondents (88%) indicated that IPLS courses are offered by their department. Respondents indicating that there were *no* IPLS courses offered (N=14) gave a variety of reasons, including (1) lack of incentive, (2) needed support and guidance to create one, (3) enrollment issues, or (4) an intent to create such a course soon. Those who do have IPLS courses at their institution were asked to describe their IPLS courses. Results given below.

"Is there a standard textbook used?" All indicated that there was a standard textbook used. A list is below, but due to some unclear answers (e.g., "Knight") and overlap of textbook authors, there may be inaccuracies.

Texts used by five or more institutions

- College Physics (Knight, Jones, Field): N=14
- Physics (Giancoli): N=10
- College Physics I and II (Serway and Vuille): N=5
- Physics for Scientists and Engineers (Knight): N=5
- Physics (Cutnell & Johnson): N=5

Texts used by 2-4 institutions

- College Physics (OpenStax): N=4
- College Physics (Wilson, Buffa, Lou): N=3
- Fundamentals of Physics (Halliday & Resnick): N=3
- College Physics (Serway and Vaughn): N=2
- College Physics (Giambattista, Richardson, Richardson): N=2
- College Physics (Urone and Franklin): N=2

Texts used by one institution

- Physics for the Biological Sciences (Williams et al)
- Matter & Interactions
- Physics (Walker)
- Physics for Everyday Phenomena
- Essential College Physics (Rex and Wolfson)
- Introduction to Biological Physics (Franiklin, Muir, et al)
- Sears & Zemansky College Physics (Young)
- Comparative Biomechanics (Vogel)
- Biological Physics (Nelson)
- Essential Physics (Duffy)
- Physics Reasoning and Relationships (Giordono)

"What is the course title?"

The most common responses are given below.

- General Physics or General Introductory Physics (N=22)
- Physics for Life Sciences / Introduction to Physics for Life Sciences / University physics for life sciences/ Physics of the life sciences (N=17)
- College Physics or College Physics I and II (N=14)
- Introduction to Physics I and II (N=11)
- Elementary Physics / Elementary General Physics / Elements of Physics (N=3)
- Fundaments of Physics I and II (N=2)

"Please tell us a little about the IPLS courses at your institution"

Complete answers to this question are given in the Appendix for more detail, as responses are quite rich and varied. Some themes included:

- **Pedagogy:** A surprising number are using PER and interactive teaching techniques.
- **Topical relevance to life sciences:** A large number indicate that the courses do target the needs of life sciences, or that relevant examples are used, but many indicate that this needs work.

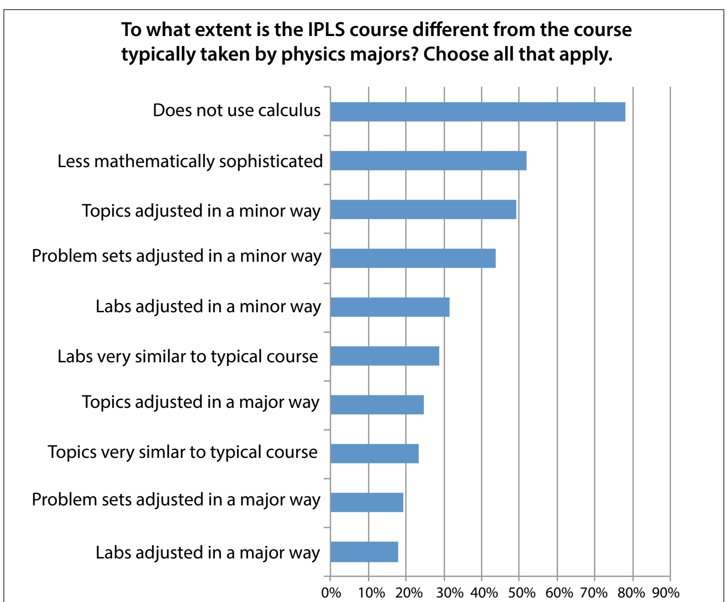
- **Appropriate to background of students:** Many indicate that the courses are too mathematically sophisticated or students lack the math skills. Some say the course is too condensed or rushed.
- **Is it working well?** Several indicate that the course does seem to be working well, but slightly more indicate that the course needs work. Some cite course evaluations as evidence, MCAT scores, education research, or the use of research-based instructional techniques, though many rely on their informal impressions.
- **Is it different from the generic physics course?** Some responses indicate that the course is indeed different, though several also indicate that the course is similar to the generic courses and not well-adapted to biology.
- **Other issues:** Several indicated that the course experience varies widely based on the instructor who is teaching it. Several also indicate low student motivation and interest as barriers.

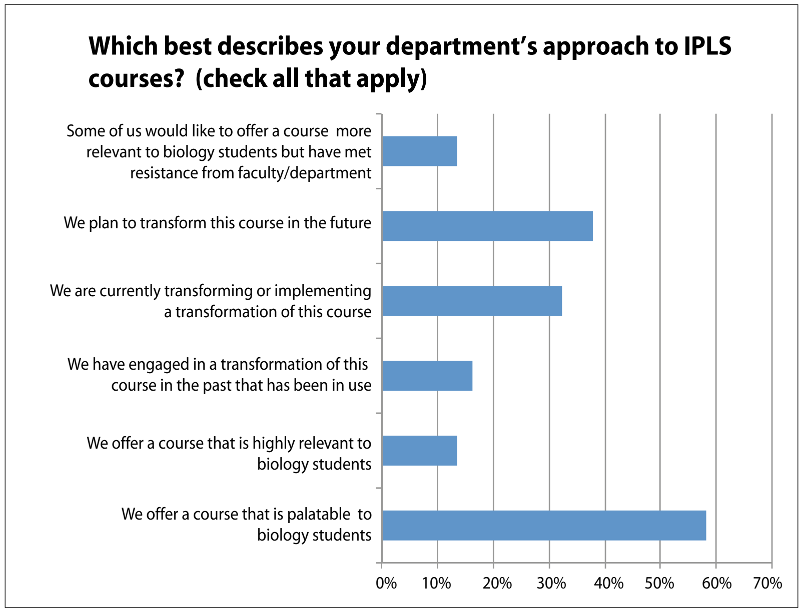
"What are the mathematical pre-requisites of your course?"

The vast majority indicated algebra/trigonometry (81%), with only 18% selecting "calculus," in addition to 12 respondents selecting "other."

"To what extent is the IPLS course different from the course typically taken by physics majors?"

Respondents could select from several different options. The most typical responses include that the IPLS course (a) does not use calculus, and (b) topics, problem sets, and labs are adjusted in only a minor way from the standard course. However, a not-insignificant portion indicated that major adjustments had been made. *Note that this question originally did not allow respondents to check more than one box – some indicated appropriate responses in the "comments" section, but some data may not be accurately reflected here due to that error.*





Departmental approach to IPLS courses

Most respondents indicated that they planned to transform their IPLS course, were currently transforming the course, or had done so in the past (87%). Thus, meeting attendees represent institutions that are actively engaged in course transformation. The majority indicate that they offer a course that is highly palatable to biology students, rather than highly relevant. A small but sizeable fraction (14%) indicate that they have met resistance to creating a more relevant course.

Challenges to transformation of IPLS courses

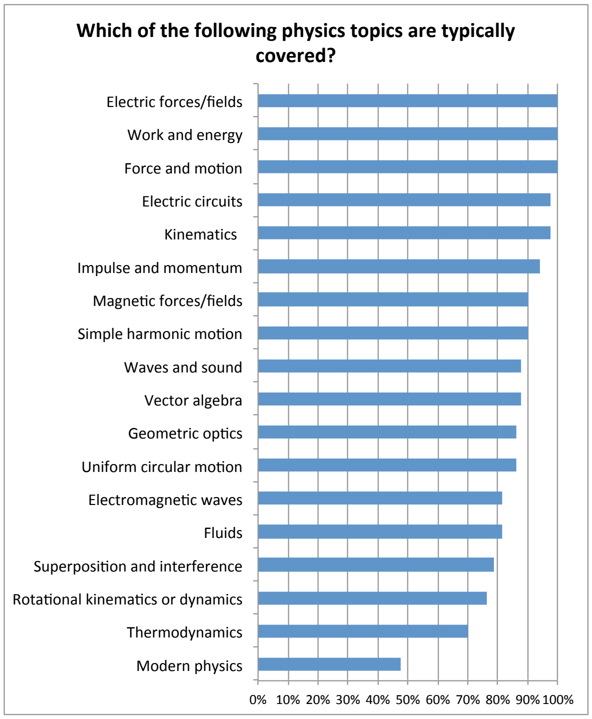
Respondents (N=74) provided long-answer responses to perceived challenges to changing pedagogy or content of IPLS courses. Common themes included, listed in rough order of frequency of mention, with most common items highlighted.:

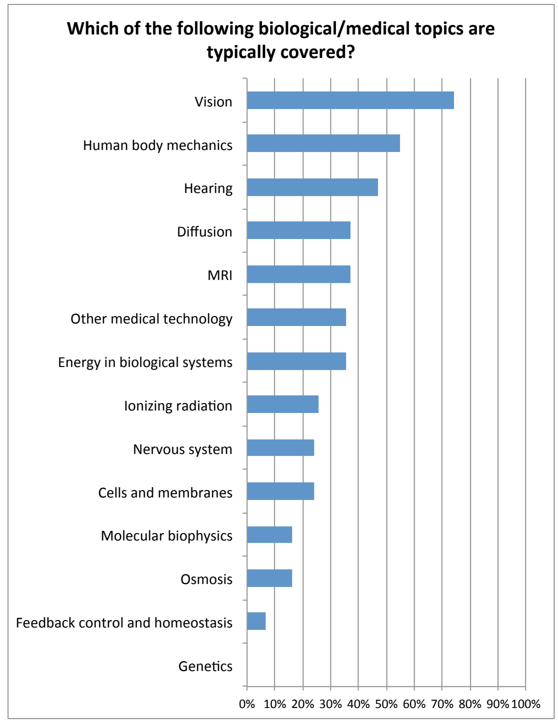
- **Time and effort** (mentioned most often)
- **Resources** (textbook mentioned several times, funding, lab space, lab equipment, lab experiments)
- **Lack of faculty expertise** in biology
- **Buy-in** (from faculty, from departments, from students)
- **Course is low priority** / there is no demand for change
- **Course requirement structure** (e.g., whether course required for life sciences, the course serves audiences other than biology majors)

Content of the IPLS course

Respondents were asked about the following physics and biological topics. As can be seen, there is far more consensus about the included physics topics than biological topics. Items included in "other" included nuclear physics and radioactivity (under physics topics).

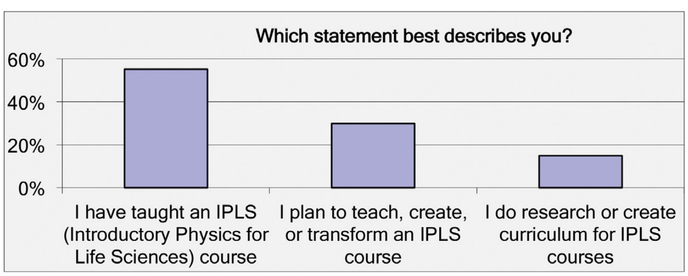
"Other" biological topics mentioned were very diverse. Several respondents mentioned that biological topics are included only superficially as examples or on homework.



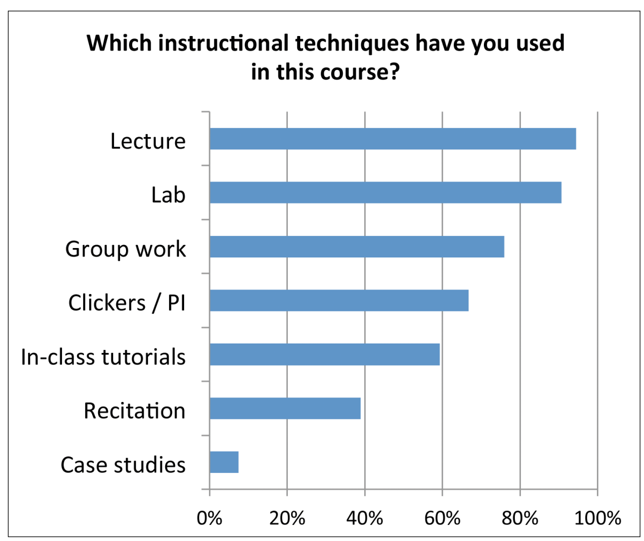


About IPLS Courses that They Teach

About half of respondents have taught an IPLS course in the past (see figure below; N=48) and were asked additional questions about their course.



A substantial number of these instructors have used interactive techniques such as group work, clickers, and tutorials.



Instructors use a variety of techniques to make the content relevant for their students in IPLS courses. Some common themes are listed here, in rough order of popularity:

- **Use examples and problems from biology and health** (most commonly mentioned). The importance of finding a textbook that offers this was mentioned several times.
- **Use examples and connect material to the real world** (not necessarily biology). Avoid abstractions, maintain student interest.
- **Alternative modes of presentation,** including independent projects, guest speakers, group work, demonstrations

- **Skip mathematically challenging examples** or explain mathematics in more depth.
- **Work MCAT problems** in problem-solving sessions or use MCAT examples.
- **Include more life-science relevant topics** (eg., fluids, thermal physics).
- **No changes made.**

Instructors cite a variety of unsolved challenges in teaching IPLS courses.

These are listed in rough order of popularity, with the most common issues highlighted, but challenges cited were very diverse. Most instructors recognized systemic issues as key, and very few took an approach of blaming students for poor background or motivation.

- **Mathematical preparation of students** (calculus, algebra, statistics, error). Addressing mathematical prep issues takes time away from biological applications.
- **Content and topics covered:** What to emphasize, what to drop, how much biology to include in a physics course. Need to reduce the number of topics, but need guidance on what to toss. Biological examples are not authentic or meaningful.
- **Addressing needs of diverse audience,** given the fact that courses serve majors other than biology, or a diverse set of life sciences students (e.g., premed and biologists).
- **Student interest and buy-in**, seeing physics as relevant.
- **Faculty issues:** Transferability of a new approach to other faculty, faculty development, lack of faculty knowledge of life sciences.
- **Increasing interactivity.**
- **Lack of instructional resources,** such as examples, textbook, labs, or other instructional materials.

Instructors cite various challenges in making changes to the IPLS courses:

- **Time and effort**
- **A good textbook,** integrating biology with a general curriculum, rather than supplements
- **Faculty buy-in** or inertia
- **Faculty development** and background knowledge
- **Structural issues,** such as student enrollment, scheduling, room layout, logistics and material management, administrative support, or diverse student body in courses
- **Instructional resources** – locating and developing

Some respondents plan to teach an IPLS course in the future (N=26).

Some relevant comments from these respondents:

- Would like to better serve the students, and know this is needed through personal experience, philosophy, or background.
- Would like to know what has worked or not worked, and areas of controversy.
- Would like to consider learning strategies and objectives for these students
- A committee is currently considering transformations, or the respondent is a department chair in a department that is transforming courses.