Report on
the Workshop on the Status of the Upper-level Physics Curriculum

June 5 – 7, 2014
Oregon State University, Corvallis, Oregon

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Executive Summary

- The Workshop, organized by Corinne Manogue and Tevian Dray, occurred over two full days and included five working sessions consisting of invited and contributed presentations, breakout discussions, and whole group discussions.
- Nearly 50 participants were drawn from a variety of institutions and had a range of expertise, ensuring the representation of diverse curricular advances, needs, and views.
- The participants were highly engaged, yielding productive discussions.
- Three working sessions were focused on the content areas of electromagnetism, quantum mechanics, and thermodynamics/statistical mechanics. A working session on the "Whole curriculum" covered other content areas, cross-cutting areas, assessment, and instructional strategies. A final working session on "Next Steps" focused on dissemination of research-based reforms.
- Specific outcomes of the workshop include:
  - increased awareness of the state and availability of upper-level curricular materials and the state of student learning using these materials;
  - suggestions for developing new materials and for education research in the upper-level courses;
  - increased connectivity among people at different institutions with different expertise.
- The workshop was an important and necessary step for the physics community to take on its way to specifying the skills and knowledge undergraduate physics majors should have upon graduation, and to specifying effective ways that these skills and knowledge can be developed.
- Workshop participants were informed of the existence of the AAPT Undergraduate Curriculum Task Force, its work to date, and its future role to inform and support the recently named Joint Task Force on Undergraduate Physics Programs.

Detailed Summary

The five working sessions were all held in Weniger Hall on the campus of Oregon State University, and were organized around the main topics/ideas as shown in the table below.

	Friday, June 6, 2014	Saturday, June 7, 2014
Morning	Electromagnetism	Thermodynamics/Statistical Mechanics
Afternoon	Quantum Mechanics	Whole Curriculum
Evening	Banquet	Next Steps

A typical session would consist of a group discussion and invited presentation, and then contributed presentations and breakout discussions (the order of these session elements was flexible). The breakout discussions were followed by whole group discussions, during which the breakout groups reported their main points. The breakout groups were organized along particular topics or questions, such as:

- Student difficulties: mathematical or conceptual
- Making connections to the real world
- What curricular materials exist or are needed?
- What does sense making look like for this topic?
- What does problem solving look like for this topic?
- What research methods or theoretical perspectives apply to this topic?

The preceding list is not comprehensive because the presentations elicited responses that shaped the breakout groups. For example, the working session on quantum mechanics included a breakout group on the coherence/content of modern physics and quantum mechanics.

Brief descriptions of the sessions are given below. These descriptions are necessarily incomplete because it was not possible to roam between breakout discussion groups effectively. Furthermore, *these descriptions are only from the point of view of the author*; others experienced the workshop differently and would surely have taken away different messages and emphases.

Complete tables listing the participants and presentations are given at the end of this document. It is worth noting that Corby Hovis of the National Science Foundation gave a presentation on the new IUSE program in the Division of Undergraduate Education. Additionally, Henri Jansen, the Department Chair of the Oregon State University Department of Physics, gave a presentation about curricular reform that encouraged us to think about how to support each other in our teaching, get out of our silos, and focus on student learning.

Electromagnetism Session:

Presentations were given by Pollock (invited), Wilcox, Ryan, Zwolak, and Hinrichs. The Science Education Initiative model of course transformation involves collaboratively identifying learning goals, assessing what students learn, and identifying and implementing instructional strategies that improve student learning. It has been found that interactive engagement strategies (e.g., tutorials, clickers, class activities, etc.) improve student learning. Implementation requires collaboration, data collection, and support. An assessment instrument exists for upper-level electrostatics (CUE) and is being developed (CURrENT) for electrodynamics (e.g., 'second semester of E&M'). Different curricula (e.g., U Colorado @ Boulder and Oregon State) can yield different results on the CUE.

Breakout group discussions yielded various observations and suggestions. It was observed that there is near-universal adoption of a particular text for this content; the curl is hard to understand; symmetry approaches and the field concept need more emphasis; spiraling helps (re: math); materials are available from U Colorado, Oregon State, and MIT; non-developers need a forum to share experiences and ratings of materials; sense making in E&M encounters the roadblocks of abstraction and math; our values must be expressed in our assessments; and students need a problem-solving framework. It was suggested that a context-rich database of E&M problems based on real systems/phenomena (e.g., applications and lab experiments) should be developed; and research to analyze homework (written or video) could be interesting.

Quantum Mechanics Session:

Presentations were given by Singh (invited), McIntyre, Tate, Passante, and Sadaghiani. As is the case for E&M, interactive engagement strategies have been found to improve student performance. Although much educational research (including assessment) and materials development has occurred in QM, the additional difficulties in learning QM (compared to E&M) continue to provide opportunities for further research. Over time, a "spins first" approach has evolved and become more widely supported and adopted although it may need a strong modern physics prerequisite. Students find research-based tutorials to be useful, but instructors are hesitant to adopt the tutorials because of the trade of coverage for understanding.

Breakout group discussions yielded observations and suggestions. It was observed that active research in physics has evolved to match the "spins first" approach. It was noted that the relative lack of intuition students bring to this topic makes it challenging to develop the skill of self-checking. It was also noted that conceptual difficulties included interpretation of the wave function, the meaning of notation and of Hilbert space, the distinction between explaining and predicting, the difference between interpretations (Copenhagen and others), and what can be asked in QM. Additional challenges include making connections to the real world, understanding uncertainty versus commutation, and the difference between representations and bases. With regard to modern physics, it was noted that there is no consensus on what belongs in the course of that title; decisions are made locally according to various needs. Nonetheless, quantum physics (literally: the photoelectric and Compton effects; 1D non-relativistic Schrodinger equation solutions) seemed common to all modern physics courses.

Thermodynamics/Statistical Mechanics Session:

Presentations were given by Meltzer (invited), Loverude, Thompson, and Roundy. It was noted that the few-week treatment of thermodynamics often found in the introductory course does not build adequate understanding of fundamental concepts; students are often confused about entry-level concepts. Furthermore, no upper-level assessment exists for thermodynamics although there exist assessment instruments for heat and temperature concepts, and well-tested individual items. A conceptual assessment is under development (Singh). General issues include: everyday language definitions (e.g., of “heat”) conflict with physics definitions; difficulties with diagrams and symbols cause particular trouble in thermal physics; approximations and idealizations common to thermal physics are intensely confusing for most students; and constraint conditions are ignored, and, consequently, relationships are overgeneralized. The Thermal Physics Project is a 15-year project to study student learning of thermal physics concepts and develop instructional materials based on research. This project has produced many tutorials and also structured worksheets. It was noted that there is a choice to be made regarding content: specifically, whether statistics concepts will be employed from the beginning, or not. Some instructors choose to start with statistics and work into the thermal physics. It was noted that the transition to the upper-level may be made more challenging by environment (welcoming or not; helpful to non-traditional or not; etc.). It was also noted that thermal physics cuts across disciplines (e.g., chemistry, chemical engineering, mechanical engineering) and that the approach of other disciplines is qualitatively different. For example, engineers are less exposed to analytical state functions but more exposed to measured samples of state functions (e.g., NIST ‘steam tables’), which alters the approach. Finally, it is possible to make at least some of the content of thermal physics accessible through simple experiments (e.g., the partial derivative machine; the heating of a rubber band).

Breakout group discussions yielded observations and suggestions. It was noted that more connections to the real world could be helpful for developing various skills and for exposing physics students to the engineering approach; that the partial derivative machine was very useful and should be disseminated more broadly; that it is necessary for students to gain facility in explicitly stating assumptions underlying a calculation; and that statistical mechanics is different and difficult.

Whole Curriculum Session:

Presentations were given by Gire (invited), Bautista, Burciaga, Zwickl, Belloni, Roundy, Loats, Rundquist, De Pree, Ambrose, Brahmia, Wangberg, Dray, and Ives. It was noted that the question "What do we want physics majors to know/do when they graduate?" may be more difficult to tackle in practice because of the 'grain-size' intended for the answer, the translation to instructional practice, the difficulty of assessment, and the difficulty of thinking across courses. Possible strategies for thinking across the curriculum (i.e., courses) include thinking across short sequences of related courses, developing narrative threads, framing with mathematical concepts/techniques, practicing disciplinary skills, and using intergenerational teams of faculty. Faculty collaboration is critical. It was noted in discussion that "thinking like a physicist" has been considered, but still needs better definition. The contributed presentations ranged over laboratories, computation, classical mechanics, resources for relativity, vector calculus, and surfaces, specific instructional strategies, helping students with careers, being more mindful of the math-physics connection through blended instruction, and exercising care when interpreting assessment results.

Breakout group discussions yielded observations and suggestions. One group reported on the difference in the viewpoints of mathematicians and physicists regarding math (e.g., regarding "rigor"; we were encouraged to adopt the view that physicists simply do math "differently"). A second group discussed the use of video assessment of homework, and the issue of subjectivity was raised. It was noted that authentic/inauthentic assessment does not rigidly correspond to objective/subjective assessment tasks. The group I was in did not report out, but had considered laboratory: again, the need for a community-sourced, context-rich database of questions would be very useful.

Next steps session:

Presentations were given by Behringer, Dancy, Dubson, and Martinuk. It was noted that the AAPT UCTF was started from the bottom through the Committee on Physics in Undergraduate Education and has worked to identify information needed to reasonably characterize and compare programs and departments, and has also worked to develop recommendations in the cross-cutting areas of laboratories and computation. It will move into a support role as the J-TUPP becomes active this fall. It was noted that research-based instructional strategies have not been widely adopted, and the usual 'develop and disseminate' model has proven ineffective because it assumes faculty can easily change if they want to, and ignores structural/environmental barriers and does not adequately acknowledge implementation difficulties or support faculty. It is recommended that modifiable materials be made available, and that communities of adopters be developed and supported. The story of reform at U Colorado @ Boulder was described: it all began with the large introductory courses, and spread upward. Its success has depended on strong support from the top, and hard work from the bottom; the middle tends to go along with what is working (as shown by data; this highlights the need for data). It was strongly stated that teachers must be respected and never pressured to take up reform-based methods; the latter strategy is not effective. Finally, it was noted that the PER User's Guide is continuing its evolution toward being a one-stop shop for PER perspective and materials, and as a community-building tool. The whole group discussion that followed concentrated mainly on the difficulties of implementing and sustaining reform.

SUPC Workshop Participant List (48 participants; 33 distinct organizations)

Contact information redacted in the public report

Name	Institution	E-mail Address
Brad Ambrose	Grand Valley State U	
Manuel Bautista	Western Michigan U	
Ernie Behringer	Eastern Michigan U	
Mario Belloni	Davidson C	
Susan Blessing	Florida State U	
Suzanne Brahmia	Rutgers U	
Kerry Browne	Rivendell Academy	
Juan Burciaga	Mount Holyoke C	
Danny Caballero	Michigan State U	
Hunter Close	Texas State U	
Abigail Daane	Seattle Pacific U	
Melissa Dancy	U Colorado @ Boulder	
Erin De Pree	St. Mary's C of MD	
Tevian Dray	Oregon State U	
Mike Dubson	U Colorado @ Boulder	
Liz Gire	U Memphis	
Julie Greenwood	Oregon State U	
Mark Haugan	Purdue U	
Paula Heron	U Washington	
Brant Hinrichs	Drury U	
Corby Hovis	NSF	
Paul Irving	Kansas State U	
Joss Ives	U British Columbia	
Henri Jansen	Oregon State U	
Jeff Loats	Metropolitan State U	
Michael Loverude	Cal State Fullerton	
Corinne Manogue	Oregon State U	
Sandy Martinuk	Cognition Technology	
Bruce Mason	U Oklahoma	
David McIntyre	Oregon State U	
David Meltzer	Arizona State U	
Robin Pappas	Oregon State U	
Gina Passante	U Washington	
Thomas Planchon	Delaware State U	
Steve Pollock	U Colorado @ Boulder	
David Roundy	Oregon State U	
Andy Rundquist	Hamline U	
Qing Ryan	U Colorado @ Boulder	
Homeyra Sdaghiani	Cal Poly Pomona	
Chandralekha Singh	U Pittsburgh	
Emily Smith	Oregon State U	
Janet Tate	Oregon State U	
John Thompson	U Maine	
Aaron Wangberg	Winona State U	
Eric Weber	Oregon State U	
Bethany Wilcox	U Colorado @ Boulder	
Ben Zwickl	Rochester Inst Technol	
Justyna Zwolak	Oregon State U	

Tables of Speakers

Electromagnetism Session:

Speaker	Presentation Title
Steve Pollock (U Colorado @ Boulder)	Research-validated approach(es) to transforming upper-division E&M
Bethany Wilcox (U Colorado @ Boulder)	Tools for Educational Transormation in Upper-division Electricity and Magnetism
Qing Ryan (U Colorado @ Boulder)	CURrENT: Colorado UppeR-division ElectrodyNamics Test
Justyna Zwolak (Oregon State U)	Revealing differences in curricula using the CUE diagonostic
Brant Hinrichs (Drury U)	PER in Junior-level E&M: My General Approach + A Specific Example

Quantum Mechanics Session:

Speaker	Presentation Title
Chandralekha Singh (U Pittsburgh)	Improving Teaching and Learning of Quantum Mechanics
Dave McIntyre (Oregon State U)	Quantum mechanics in the Paradigms curriculum
Janet Tate (Oregon State U)	Some observations from teaching in the Paradigms curriculum
Gina Passante (U Washington)	Tutorials in Physics: Quantum Mechanics
Homeyra Sadaghiani (Cal Poly Pomona)	From Spin-First Approach to Quantum Mechanics Concept Assessment (QMCA)

Thermodynamics/Statistical Mechanics Session:

Speaker	Presentation Title
David Meltzer (Arizona State U)	Overview: Research on Student Learning of Thermal Physics
Michael Loverude (Cal State Fullerton)	No title (Physics 310 at CSUF)
John Thompson (U Maine)	Research on the learning and teaching of upper-level thermal and statistical physics at the University of Maine
David Roundy (Oregon State U)	Connecting math with experiment in thermal physics

Whole Curriculum Session:

Speaker	Presentation Title
Liz Gire (U Memphis)	Overview: Thinking Outside “The Course”
Manuel Bautista (Western Michigan U)	Lesson Study Project on Improving the Modern Physics Laboratory (PHYS 3100)
Juan Burciaga (Mt. Holyoke C)	Curricular Objectives and Assessment Protocols for the Introductory Physics Laboratory
Ben Zwickl (Rochester Inst Technol)	Transforming upper division labs at the University of Colorado Boulder
Mario Belloni (Davidson C)	Using Physlets and OSP for Teaching Astronomy and Physics
David Roundy (Oregon State U)	Integrating computing into the upper division
Jeff Loats (Metropolitan State U)	Just in Time Teaching
Andy Rundquist (Hamline U)	Physics Education Engineering
Erin De Pree (St. Mary’s C Maryland)	Career Moments for Physics Students
Brad Ambrose (Grand Valley State U)	Using research to investigate and enhance learning in intermediate mechanics
Suzanne Brahmia (Rutgers U)	Mathematization as a framework for developing reasoning in introductory physics courses
Aaron Wangberg (Winona State U)	Raising Calculus to the Surface
Tevian Dray (Oregon State U)	The Geometry of Vector Calculus – and Special Relativity; and Bridging the Gap between Mathematics and the Physical Sciences
Joss Ives (U British Columbia)	Queuing and Question Reliability

Next steps session:

Speaker	Presentation Title
Ernie Behringer (Eastern Michigan U)	The AAPT Undergraduate Curriculum Task Force: Genesis, Work, and Next Steps
Melissa Dancy (U Colorado @ Boulder)	Educational Transformation in Higher Education STEM
Mike Dubson (U Colorado @ Boulder)	Transforming Teaching in a Physics Department: Educational Reforms that Stick
Sandy Martinuk (Cognition Technology)	Web-based dissemination and collaboration: The future of the PER User’s Guide

Special Presentations:

Speaker	Presentation Title
Corby Hovis (National Science Foundation)	No title (Overview of the IUSE program)
Henri Jansen (Oregon State U)	Curriculum change from a departmental point of view