Proposal for Undergraduate Teaching in Physics & Astronomy

Oct. 26, 2007

Background

Physics & Astronomy at UBC has demonstrated a high level of commitment to, and success in developing effective new teaching methodologies over the past decade. Initiatives have been informed by physics education research that is published, conveyed by expert speakers invited to the department, and/or passed on by department members who have attended AAPT, NSTA conferences, educational workshops sponsored by NSF and equivalent education sessions at the annual Canadian Association of Physicists congresses. Examples include the introduction of peer-teaching techniques in many of our first year classes, the development of project-based courses such as the Engineering Physics Instrument Design Lab, and the department's participation in the team-taught first year program, Science One. Beginning two years prior to the advent of CWSEI, members of the department involved in first year teaching have met regularly to discuss pedagogical issues and best practices, and another group has been defining overall learning goals of our programs. The first year group coordinates the development of projects funded by TLEF and Skylight, including a new TLEF-funded proposal that is reconfiguring our investment in first year laboratories and tutorials to make more efficient use of our teaching time. There has been considerable work already on defining course goals and assessment tools for PHYS 100, 101 and 102. On the programmatic front, we have had considerable success in the development of a biophysics program and the newest initiative is a proposal for a joint Physics/Education degree tailored to students looking towards a career in K-12 teaching, something that has potential for long-term impact.

2007 Activities

Beginning in 2007 a number of activities were undertaken that were aimed at the particular goals of the CWSEI, with partial funding made available for pilot projects. The work undertaken was chosen to establish a base from which to grow a larger program. The three key activities that have been underway are the development of a Teaching Assistant training program, the development of a computer archive, and an initial attack on learning goals and course reform for a small subset of the department's course offerings. All three of these projects were chosen at the beginning because of their importance in the long-term sustainability of this initiative. In particular, the new activities that must be undertaken by faculty members must be mitigated by an increased role for our graduate students, and the T.A. training will get these students ready for greater responsibilities. The archive will ensure that any improvements made to a course actually make it easier for subsequent instructors to teach the course. The small number of pilot courses has provided an opportunity to test the T.A. training, to test the course archive, and to provide feedback on the resources needed to tackle a course.

The T.A. training was spearheaded by our graduate student Mya Warren, who assembled a strong team to develop and run a two-day teaching workshop at the beginning of the fall 2007 term. This initial training effort was mandatory for our incoming graduate students and was a significant contribution to the restructuring of our first year offerings. A system of mentor T.A.s was initiated to provide a structure in which senior graduate students can oversee the graduate students in our first year courses and help to develop their teaching skills. Adjustments to the T.A. training program are under way and will be enhanced by a new graduate course in pedagogy in Physics&Astronomy.

A test version of an archive for teaching materials was developed by one of our IT staff Gerry Grieve, in consultation with Chris Waltham. The goal is to have an archiving tool that helps in the implementation of course development and sustains it by making the job easier for subsequent instructors who take on a course. The content of the archive will include
- Updated info from UBC Calendar, SISC, Classroom Services
- Tree to related courses, program
- Instructor, TA info, office hours etc.
- Learning goals
- Term calendar
- Notes, resources
- Exams, assignments, solutions
- Diagnostics, results
- Course evaluations, results
- Notes for other teachers

The archive is currently being tested and fine-tuned by Chris Waltham for Science One, and by Jaymie Matthews, who is making a major contribution to the database while simultaneously tackling ASTR 101 and ASTR 310. In addition to these courses, PHYS200 and the lab for PHYS 107/ScienceOne are also making early efforts at developing learning goals and teaching techniques. The largest project on a particular course thus far is a major effort on the introductory course PHYS 100. The course is introducing physics concepts within themes relevant to contemporary life and real world problems such as energy usage and global warming. The lectures already make use of a PRS system and the labs and tutorials have been streamlined together and emphasize context-rich problems, similar to those developed by Heller et al. at the University of Minnesota. These problems are structured to reinforce the development of a structured problem-solving methodology. The team working on PHYS 100 consists of Andrzej Kotlicki, Fei Zhou, Georg Rieger and Sandy Martinuk. They are also employing our first use of ‘mentor T.A.s’ and have the further assistance of Sandy Martinuk, the department’s first graduate student to tackle a research project in physics pedagogy. With Sandy’s involvement, the course has already been through a first round of pre- and post-testing, plus interviews with individual students.

All of these projects serve two broad purposes in addition to individual course development: they provide a testing ground for our archival system and they have provided a useful measure of the resources needed in subsequent stages of or course development. For the upcoming years we propose to implement three key elements in the revision of further sets of individual courses: specification of learning goals, development of new teaching methods, and new evaluation techniques. We also will put in place the means to weave this course-by-course approach into broader programmatic goals.

1. Specify learning expectations

Learning goals will be specified in consultation with graduate and undergraduate students, faculty, and employers; iterated year to year. Each course uses a template that breaks specific goals into categories such as:

- Technical information (e.g. conventional syllabus topics and numerical experience)
- Conceptual understanding
- Contextual understanding (relevance to everyday life, current research etc.)
- Psychological impact (students leave with a good impression of the subject)

- Ability to communicate understanding
- Ability to solve unfamiliar problems
- Lab skills
- Teamwork

The students will be presented with their learning objectives at the beginning of the course, and lectures will frequently refer to these elements. These objectives should be clearly understood by the students, instructors and teaching assistants, and should help "make connections" between topics, which is the basis of true understanding.

The development of these learning goals is a priority in this program and will be a priority for all of the course offerings in Physics&Astronomy.

2. Develop new/modified methods for getting students to learn effectively

While the development of learning goals for all courses can be tackled immediately and in parallel, the development and application of new teaching methods and evaluation tools will be constrained by the resources available. Each year, courses will be chosen to receive extra resources, such as postdoctoral fellows, for the development of new instruction and assessment tools. The new tools might include:

- **Simulations** Increase the use of simulations and video-aids for pre-labs and homework assignments. This is especially necessary in subjects where the mathematical or experimental complexity often obscures the concepts (e.g. diffraction in optic)
- **Adaptation of teaching techniques from other areas** For instance provide the necessary support materials so that personal response systems can be used in all classrooms and laboratories.
- **Development of integrated, experimentally-oriented learning projects**
- **Relevant Examples** Provide real life examples and relate course material to technology, sustainability, current research -something that students recognize or find interesting and important.
- **On-line homework** Many texts now provide data banks of on-line problems and “skill builders”, these are self-paced and provide immediate feedback to the students. These have proven effective in our first year courses, and should also have a positive impact beyond first year.
- **Reading assignments** Use these to expand on concepts in class. Introduce pre-class reading assignments – Web-CT can be used to provide student feedback and also to assess student’s understanding. This will increase the involvement of students in the learning process.

3. Develop appropriate assessment mechanisms:

From the outset, we have recognized that some of the greatest challenges lie in the assessment of our teaching and the students’ learning. The four principal purposes for assessing teaching and learning are to determine:

1. The extent to which students mastered the learning outcomes specified for a particular course or program?
2. How effective the course/program was at helping students achieve the learning outcomes.
3. How the learning/teaching experience has affected the attitudes of students and instructors

4. The "long term" impact (could be of a first year course in 4th year, or of their overall education after graduation)

For most courses at the present time, the extent to which students master the material is assessed through exams, problem sets, projects etc. which are assigned marks that go towards each individual student's final mark in a course. Although things are changing, traditionally these marks are based on assessing the technical skills learned by the students. This testing only partially addresses the first point and does not address any of the other three purposes noted above. Current student evaluation forms serve primarily to address point 3, and nominally number 2 (from the students' perspective) and this information is used to assess the performance of the instructors in a way that does not address the actual effectiveness of the instruction. Point 4 is currently not formally addressed at all. The proposals below are aimed at better addressing all four of these assessment aims.

- **Student teaching evaluations.** Regarding items 2 and 3, from the students' perspective, a new four-component student evaluation form is being developed university-wide. It will have a set of questions that are formulated by the university, the faculty, the departments, and the instructors. The department and instructor sections of these new forms should allow us to tailor the questions to get better quality feedback that would help us identify and address common problems, and also to obtain some measure of the impact that individual courses have on student's attitudes towards science. Example departmental questions would be;
    - Were the learning objectives for this course made clear at the outset?
    - For each learning objective (make available as part of the questionnaire), rank the degree to which you feel your learning has met that objective.
    - Would you suggest adding or removing items from this list of learning objectives? (Why?)
    - Did you enjoy the course? (Why/why not)
- **Evaluation by Teaching Assistants.** TAs will explicitly monitor student performance and attitudes throughout the course, and provide formal feedback to the instructors on a regular basis. This would help identify which concepts or topics are particularly challenging, or what teaching styles are generally viewed as ineffective. Instructors should be encouraged to do their own polling, but students might be more forthcoming with TAs.
- **Mid-Term Evaluations.** Instructors have already been encouraged to perform mid-term evaluations to allow for corrections to be made before the end of a course. Mid-term examinations are a part of this, but other information can be gleaned from the students through interviews and teaching evaluations tailored to each course. This step will be particularly important when we engage in substantial changes to courses and need to make some assessment before the course is complete.
- **Evaluation by Instructors.** Establish a departmental course evaluation form that instructors have to fill out at the end of the course. This could be coupled with formal debriefing sessions for related courses.

With clearly articulated learning outcomes for our various programs, each year of the programs, and individual courses, various ways have to be found for assessing the degree to which these desired outcomes have been met. A very small set of assessment tools has now been developed, such as the Force Concept Inventory (FCI), and where such tools exist and are already validated, we will take advantage of them. Judging by the degree of effort that went into the establishment of the FCI, the evolution of our current assessment tools will be the most challenging part of teaching reform, and will require an investment at a scale that is not yet perfectly clear, but will certainly require the personnel afforded by the CWSEI. Fortunately, conceptual testing is a major growth area in physics and astronomy in North America, so the available tools are in a rapidly improving state. Furthermore, many of our course offerings, especially in the upper-level courses, may need assessment tools that are not such a great deviation from the current student-mark-based assignments and tests. Some examples of where our own effort will be placed in this regard are

- **Develop FCI-like tests for concepts at levels beyond first year**. These could ultimately be cumulative, so that the same concepts are tested and retested, but new concepts are added at each level. By the end of their programs, these should provide a comprehensive measure of their mastery of critical physical concepts.
- **Include an oral component, potentially in a group format, as at least one component of an overall year-by-year assessment.** The types of questions asked could aim directly at testing their ability to identify concepts from different courses that are relevant to questions that go beyond course boundaries.
- **Develop year-by-year, program-by-program "entrance refresher questionnaires" that try to ascertain how students retain and evolve their command of basic physics concepts**. These would not be used towards the students' mark (or minimally so), but more as an assessment of the learning objectives beyond the course level. Such program-wide year-to-year testing may provide a more efficient means of assessing the success of our efforts to improve learning outcomes and would move us towards an understanding of the longer-term benefits to the students.

Development and Coordination at the Programmatic Level

Substantial challenges lie in taking this course-by-course approach and moving into the area of programmatic goals. One step will be that for each course, we will also develop a list of skills expected of the *incoming* students and will help identify areas where these expectations do not match the present reality. At the single course level, this will make these expectations clear to both the students and instructors. It will also help in meshing together the learning goals of individual courses into a higher-level learning expectation template for each "program"; e.g. first year, majors, honours, engineering physics and astronomy. This meshing into program goals will necessarily entail coordination with other departments, especially Mathematics, which is crucial for Physics&Astronomy, but also other programs that in turn require our department's courses. We will establish meetings between these various parties each year to better synchronize the learning in each program.

As part of our ongoing teaching initiatives, the department is already well into the task of developing overall learning objectives for each program, which will help in fine-tuning the objectives of individual courses. These overall objectives take the form of a mastery of knowledge and exposure to ideas that will prepare the graduate to do x, y, or z. Once generated, these must be readily accessible, and students and faculty will be responsible for being aware of their content. There will be a process by which instructors and TAs for the courses can communicate and exchange ideas, and the connectivity of the course within a year and between years will be emphasized. We will group courses (e.g. biophysics, engineering physics, astronomy, etc.), and conduct mid-term and end-of-term "debriefing sessions" with instructors and TAs that taught any of the included courses that year. A mechanism for coordinating the programmatic level is already in place with a faculty member responsible for each of our specialty programs (Astronomy, Biophysics, Engineering Physics) as well as someone in charge of each year of the main physics streams.

Sustainability of reforms

As outlined above, the resources of the CWSEI will facilitate the development of new teaching and assessment tools. Ultimately, the success of this renewal process will be determined by the degree to which all faculty, instructors and TAs are able to effectively approach their teaching assignments in a well-defined context that they have played a part in developing. Three mechanisms will help assure the sustained nature of this renewal: an easily accessible repository for all course materials, a greater reliance on the capacity of well-trained Teaching Assistants, and some key features of the departmental culture. One essential ingredient is a professionally designed and implemented repository for information on teaching (resources, goals, assessment tools), which might best be integrated with the current demo room, to create a generalized demo room (physical and virtual). To allow all faculty members to participate, and feel they are part of the process, mechanisms for establishing learning goals, and analyzing the effectiveness of each course in the context of the respective program(s), will be applied to all courses from the outset. As was mentioned in the preamble, this repository now exists and will be tested and improved to the point where it is the natural tool for all faculty course instructors.

Regarding the importance of the contribution of our T.A.s, two changes are already in place. The department is already moving away form using large numbers of faculty hours to run tutorials and labs. This is intended to free up some faculty resources over the long term and is being enabled by the development of a T.A. training program and a system of mentor T.A.s. Further improvements to the T.A. training, including a new graduate course, are being developed. For the mentor T.A.s, we will be moving to a system where graduate students actually submit applications for these positions.

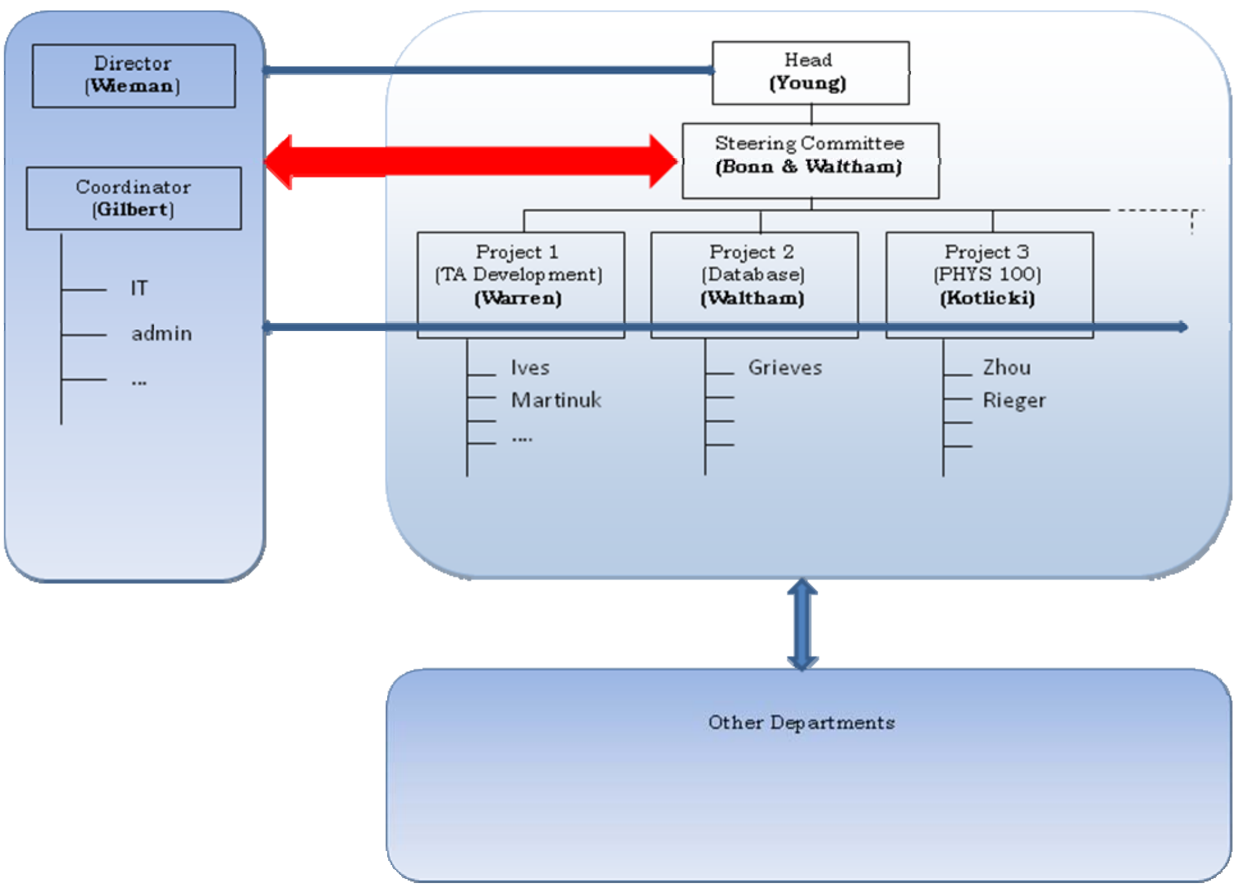
Department Culture re: UG Education

The third aspect of sustainability of the program relates to the overall teaching culture of the department. The substantial momentum already established through three years of committee discussion, the first round proposal, the endorsement of that proposal through numerous department meetings, and the specific progress made over the last several months on TA training, the web-based course resource tool, curriculum reform, and the revision of PHYS 100, PHYS 200 and ASTR 201 and ASTR 310, will naturally increase as more is learned from our experiences, and more resources are made available through the funding of this proposal. To help maintain the required focus, Undergraduate Education will be a key topic discussed by all faculty members at the upcoming departmental retreat in December 2007. Chris Waltham is leading the UG Group, which is currently assembling data, and meeting to discuss all factors that influence the learning achieved by our undergraduate students (who will participate in the process). The CWSEI initiative will be a major component of that discussion, and the report of the UG Group, informed by discussion at the retreat, will become the UG chapter of the department’s 2008 Academic Plan. It will address goals, practices and assessments.

Once the web-based course resource tool is fully developed, and additional learning goal workshops (and inspirational talks like Eric Mazur’s) are given, the vast majority of instructors will use this information and the tools to enrich their students' learning experience. We are already seeing evidence of this outside of the targeted courses for this term. As specific courses come up for substantial revision, the instructor in charge will be given additional "buyout brownie points" to recognize the increased workload, and in most instances they will also be given the support of one of our newly hired PER development RAs. From discussions over the past year, there are some natural subject groupings with their own special issues that can likely benefit from a coordinated approach that spans a number of our current courses. This will serve to draw a broad spectrum of the department into the process. The first attempt to systematically review all of our course offerings will take place in early 2008, based on student and instructor feedback from the Fall 2007 courses.

Two other programs will help to encourage faculty members' participation. We will develop a workshop for any interested faculty who are launching into the task of a CWSEI-related course reform. This workshop will be developed in concert with the CWSEI office, covering essential tools such as the development of learning goals and techniques for interviewing students to probe their grasp of learning goals and their misconceptions. Another way to encourage involvement will be to assign new department members to multi-section courses such as our first-year offerings. This is not typical practice, but will be very beneficial as a means of mentoring new faculty members and instructors.

Management Structure for the Initiative



The figure above illustrates how the CWSEI-specific projects have been coordinated in the department over the past several months. The head meets regularly with the steering committee, and has ad hoc discussions with people in the CWSEI and other departments. He also keeps the department updated with information about the projects at faculty, staff and student-liaison meetings. Most of the specific coordination and oversight of projects is done by members of the Steering Committee, who meet regularly with CWSEI, and occasionally with people from other departments. Each specific Project has a designated leader who reports to the steering committee, and some Project personnel also interact directly with CWSEI personnel.

This organizational structure has worked quite well from the department's perspective. It could be tightened up slightly, by formalizing the relationship between Project Leaders and the Steering Committee. Anticipating the expansion proposed herein, there would be a desperate need for one experienced, full-time person to augment the Steering Committee, taking over most of the logistical aspects of sound multi-project management, as well as participating directly in the development programs. The faculty members on the steering committee will then devote themselves to steering the pedagogical aspects of the overall initiative.

Timelines for Implementation

As noted in the introductory material, two key projects are already far along; the T.A. training program and the development of an archive for all course materials. A second version of the T.A. training program is under development and in the fall of 2008 it will be further enhanced by a new graduate course, worth up to 2 credits, which will extend the T.A. training activities through two terms of a student's teaching duties. The beta version of the department's archive is now in place and the rate-limiting step for further development is our need for help to populate that database. In particular, the instructors who have been engaged in our initial projects on course reform have had limited time to place all of this information into the database, a problem whose solution lies in the funding for teaching scholars that can be made available by CWSEI.

The experience in Physics 100 indicates a three-year cycle needed for work on a course that needs substantial revision of goals, content, evaluation, and teaching methods.
We see the overall process of course revision taking the following steps:

1. Set Goals. Initially at the course and lecture (or weekly) level.
   Later on coordinate to set program goals
2. Revise Content to address goals. Lecture Content, Labs, or Tutorials may need to be updated
3. Revise Summative Assessments to reflect goals. (Midterms and Final Exams)
4. If necessary, develop Other Assessments to measure attainment of goals. These may be problem-solving surveys, conceptual surveys specific to the course content, employer satisfaction surveys etc.
5. Develop course evaluations to get detailed information from the student body.
6. Analyze the results of all of the assessments
7. Archive everything
8. Go back to the goals and start again.

So far in Physics 100 we are well into working on steps 1-5. This has required a significant commitment from three faculty members and three mentor TAs, one of whom is essentially working on the course full time. We expect that it will be necessary to go through two full cycles in order to stabilize the course content and have a set of assessments in place that will accurately measure attainment of goals. Then in the third year, these assessment tools can be used for further developments that we hope will relax towards incremental changes.

With CWSEI funding, we will be able to add further courses each year to this development cycle. In the first year of full funding, we would continue with the development of PHYS 100, 200 and ASTR 101 and 310. PHYS 101 and the lab course PHYS109 will be added to the first year projects and we will begin a cycle of work on PHYS 301 and PHYS 354, the electricity and magnetism courses for Physics and Engineering Physics, respectively. In subsequent years, the steering committee, in conjunction with the faculty members in charge of each program and year, will set the priorities for further courses to be added to the program. Also, during the first year, we expect the course archive tool to be sufficiently refined that it will be useful for all faculty members, enabling them to enter the learning goals for each course as it is taught.