UNIVERSITY OF CALGARY | FACULTY OF SCIENCE

CURRICULUM REVIEW REPORT

PHYSICS AND ASTRONOMY

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Executive Summary

Background

This curriculum review of the major and honours programs in both Physics and Astrophysics (PHAS) was initiated in the Fall of 2015 by the former Undergraduate Program Director in the Department of Physics and Astronomy, Michael Wieser, and the Undergraduate Program Coordinator, Helen Werner. They coordinated the course mapping surveys of all instructors of PHAS courses. These results were collected by Kathleen Ralph, Undergraduate Project Coordinator in the Undergraduate Science Centre, and were collated into figures and tables. These data were combined with those from the Physics and Astronomy Undergraduate Student Survey (collected by the Department yearly from 2013 through 2016), the Alumni Student Survey conducted by Kathleen Ralph, the Consortium for Student Retention Data Exchange, and the 2014 National Survey of Student Engagement. The data were analyzed by the curriculum review team in the context of departmental course and curriculum outcomes, faculty-level program outcomes, and alignment with the University's Eyes High goals. All faculty members within the Department were invited to comment on two drafts.

Analysis

- Course and Curriculum Data
  For the Technical Program Outcomes identified by the Department (Knowledge of Concepts and Theories, Critical Thinking Research & Problem Solving), there is a clear evolution from D (Developing) to A (Advanced) from 200-level to 500-level courses, with a clear demarcation between 400-level and 500-level courses. This indicates that PHAS programs are generally well-scaffolded; this interpretation is borne out by detailed analysis of individual course outlines. That said, many instructors did not consistently choose I (Introduced) for courses where topics are first introduced; this partly reflects an assumption among instructors that students are better prepared than they might be, but also a widespread confusion about whether the designation represented students' understandings by the end of the course or the level at which the material was pitched to the student. For the broad-learning outcomes identified by the Department (Communication, Self-Directed Learning, and Collaboration), the trends are less clear with collaboration especially notable and frequently absent. Indeed, the perception of limited collaboration is consistently noted by students despite numerous opportunities for group work throughout the program offerings. Both written communication and self-study (mostly in the form of assignments and experimentation) are nevertheless a priority across the program. For the Ethical Understanding outcome, almost all courses were self-designated as I except for the senior-year research thesis courses, exposing a gap in the program. Individual course outcomes have been analyzed in detail, which has allowed a fine-graining of these general trends. The main new observation is that the Astrophysics courses have challenges with scaffolding content in general; the main cause is that resource limitations have historically constrained the Department to offering several core ASPH courses only every two years. As the Faculty of Science Graduate Attributes inspired and informed the PHAS program-level learning outcomes, the outcomes closely follow those discussed above. Explicitly different outcomes include Science in Society, Creativity and Curiosity, Career Skills, Sustainability, and Social Responsibility. These are largely included in the more fine-grained version of the Departmental program-level learning outcomes, but presently the majority of PHAS courses only touch on these tangentially.

- <u>Teaching and Learning Activities and Practices</u>
  Most PHAS courses are weighted more heavily toward direct instruction, which corresponds to a more traditional (lecture-style) approach to teaching, with a bias toward second- to third-year offerings which have comparatively fewer associated laboratories. That said, for a significant fraction of courses teaching methods are close to evenly distributed among Direct Instruction, Interactive Instruction, Independent Learning, and Experiential Learning, which speaks to innovative approaches to teaching at all course levels. Likewise, most PHAS courses make heavy use of exams as an assessment tool, though again a significant fraction stress the importance of homework assignments; these not only test technical knowledge, but also provide students with numerous opportunities to express themselves verbally. Early-year courses also make wide use of experiments and the TopHat (clicker) environment.

- <u>High-Impact Practices (HIP)</u>
  Twelve PHAS courses self-identified the use of HIP, including ‘Learning Community,’ ‘Community-Based Projects,’ ‘Research Project with a Faculty Member,’ ‘Field Experience,’ and ‘Senior or Capstone Project.’ The range and application of HIP is likely under-represented, as only current instructors of a given course were surveyed; in fact the range of HIP in a course varies widely with instructor. Those who didn’t employ HIP indicated ‘time,’ ‘funding,’ ‘classroom configuration’ and ‘funding for materials’ as impediments. Many others also found that HIP in PHAS courses were ‘not appropriate’ or ‘too ambitious.’ The overall impression is that the University needs to actively motivate and encourage HIP to encourage broader uptake.

- <u>Student Perceptions of PHAS Courses and Programs</u>
  The student and alumni survey data generally convey strong satisfaction with PHAS course and program offerings, consistently over the four years we have conducted the survey. That said, there are several important caveats. Students were concerned with their growth in the areas of ‘oral communication’ and ‘technical writing,’ despite numerous opportunities to express themselves verbally throughout PHAS programs, including laboratory write-ups, homework assignments, term papers, and senior and honours theses; several courses also require students to present their results, either as an oral presentation or a poster. Students perceived limited opportunities to perform independent research or skilled work, which is more accessible to later-year students. The results of survey data point to a relatively high level of dissatisfaction with opportunities for students to interact with instructors, and with their access to career advising. The most consistent cause for complaints corresponded to the paucity of optional PHAS courses available to students, especially in senior year; historically this has been due to constraints on the number of senior-year students in PHAS programs, a problem that has somewhat alleviated in recent years.

- <u>Diversity and Retention</u>
  Enrolment in PHAS programs has climbed steadily over the years and is currently at an all-time high. Yet the ratio of male to female students has been steady at 4:1 from 2010 to 2014. This is consistent with U.S. data, but is still cause for concern. One notable issue facing the Department is the exceptionally low representation of women (and therefore female mentors) among the faculty at only two full-time faculty members out of 26. That said, PHAS students appear to be highly diverse in terms of ethnicities, economic backgrounds, and religious and political beliefs, though there is a noticeable decrease in diversity with year in program. Average attrition of students from PHAS programs is found to be a factor of approximately 2.7, corresponding to a

40% retention rate. This coincides with U.S. data for college physics retention, but is still lower than it could be.

Future Directions

- Course content and delivery:
    - Content: Evaluate PHAS and MATH course content and ensure that it is well-scaffolded and integrated.
    - Ethical Practice: PHAS will explore how to incorporate ethical practice and understanding (i.e. sustainability and social responsibility) into more course offerings.
    - HIP: The PHAS department needs to explore mechanisms for, and devote resources to, promoting the use of HIP in PHAS course offerings.
    - Teaching and Learning: The Department should commit resources and concrete strategies for the promotion of creative and effective teaching and learning practices.
    - Effective Communication: The Department should consider options for extending opportunities for students to express themselves scientifically, both in written and oral formats, as this is essential in the workplace.

- Program structure and delivery:
    - Explore options for offering Astrophysics courses yearly, in order to properly scaffold the course information, and to minimize frustration.
    - The Department should explore new avenues for student engagement and career advising within the PHAS programs.
    - The Department should devote some thought to solving the persistent paucity of senior-year PHAS options.
    - The Department should explore the possibility of instituting team-based research projects.

- Benchmarks:
    - The Department must work exceptionally hard over the next few years to correct the long-standing disparity in the numbers of men and women in PHAS, both in course enrolment and the makeup of Departmental instructors and staff.
    - The Department should endeavor to determine the root causes of student attrition within PHAS programs to determine if there are fundamental (and modifiable) issues.

Overview and Context of the Programs

The Department of Physics and Astronomy is one of the oldest departments at the University of Calgary; indeed, its establishment in 1963 predates the U of C's formation in 1966. By 1971, the number of faculty members in the Department of Physics reached 22, and has remained close to this level for the next four and a half decades; the current full-time faculty complement is 26, not including adjunct and emeritus professors and professors. The department offers Undergraduate Programs in both physics and astrophysics, and Graduate Programs leading to MSc (thesis and course-based) and PhD degrees in a number of specializations. The department even has the distinction of graduating the first MSc student in the history of the University of Calgary.

Under the stewardship of faculty members and the help of dedicated support staff and graduate students, the department has developed undergraduate and graduate teaching programs that provide rigorous training and impart the intellectual adventure of physics and astronomy to new generations. Physics and Astronomy (PHAS) programs include a major and honours B.Sc. degree in Physics, and a major and honours B.Sc. degree in Astrophysics. Courses in these programs are host to students across the University, and form a core component of other degree offerings such as the major in Natural Science with a PHAS concentration. The Department's Instructor team is committed to teaching excellence and to implementing research-driven teaching practices that are proven to improve understanding and retention. The departmental undergraduate laboratories are supported by a strong team of technical staff that service thousands of students across the university as well as those in Physics and Astronomy programs. In addition to learning the core principles of physics and astrophysics, our undergraduate students obtain a firm grounding in pure and applied mathematics, computational techniques, and experimental skills. In the process, our graduating students have a variety of skills and knowledge that allows them great flexibility in choosing their future careers.

Over the course of their programs, students have numerous opportunities to conduct independent research in numerous research groups within the Department of Physics and Astronomy. Faculty members are involved in a number of research areas that are supported by many provincial and national grants and fellowships, making the department's per capita funding level one of the highest within the Faculty of Science of the University of Calgary. This allows students to have access to world-class experimental and computational facilities both here and at collaborating institutions, as well as state-of-the-art data sets. Undergraduate students participate in research through funded summer internships and as part of their mandatory senior-year thesis work.

Program Outcomes

The following eight topics have been identified by the Department of Physics and Astronomy as desired learning outcomes for students graduating from one of our undergraduate programs. These were finalized and adopted by departmental members as of April 6, 2015.

1. Scientific Knowledge:
   i) "Demonstrated competence (both conceptual and technical) in the core areas of Physics and Astronomy: classical mechanics, electricity and magnetism, thermodynamics and statistical mechanics, optics, and quantum mechanics."
      (1) Know and understand fundamental theories and models from the core areas of Physics and Astronomy: classical mechanics, electricity and magnetism, thermodynamics and statistical mechanics, optics, and quantum mechanics.
      (2) Describe and analyze physical systems employing theories and models from the core areas of Physics and Astronomy: classical mechanics, electricity and magnetism, thermodynamics and statistical mechanics, optics, and quantum mechanics.

   ii) "Demonstrated competence (both conceptual and technical) in specialized knowledge appropriate to the chosen area of study."
      (1) Know and understand fundamental theories and models from specialized knowledge appropriate to the chose area of study.
      (2) Describe and analyze physical systems employing theories and models from specialized knowledge appropriate to the chose area of study.

   iii) "Demonstrated competence in the core areas of university level Mathematics, including multivariate calculus, linear algebra, partial and ordinary differential equations, and real and complex analysis."
      (1) Know and understand multivariable calculus, linear algebra, partial and ordinary differential equations, and real and complex analysis.
      (2) Explain physical principles by applying appropriate mathematical methods to produce a mathematical model of the problem.

   iv) "Demonstrated competence in analytical, numerical/computational, and experimental methods."
      (1) Know and understand analytical, numerical/computational and experimental methods.
      (2) Implement and evaluate the use of analytical, numerical/computational, and experimental methods.

v) “Demonstrated knowledge of the historical development of physical theories, models, experiments, and inventions.”
   (1) Know the historical development of physical theories, models, experiments, and inventions.
   (2) Describe significant developments of physical theories, models, experiments, and inventions and how they impact our understanding of the Universe.

vi) “Demonstrated knowledge of the impact of physics on society and the natural world both locally and globally.”
   (1) Recall examples of how physics has had an impact on society and the natural world both locally and globally.
   (2) Hypothesize the potential that discoveries and new knowledge in physics could have an impact on society and the natural world both locally and globally.

2. Critical Thinking:
   i) “Practised in the ability to assess data and information in order to form scientifically-based arguments and critically evaluate conclusions based on models of the physical world.”
      (1) Assess data and information in order to form scientifically-based arguments and critically evaluate conclusions based on models of the physical world.

   ii) “Demonstrated ability to interpret and model physical systems in order to draw conclusions and make predictions.”
      (1) Interpret and model physical systems in order to draw conclusions and make predictions.

3. Research and Problem Solving:
   i) “Demonstrated ability to apply Scientific Knowledge to successfully solve new physical problems or address ne physical situations.”
      (1) Apply Scientific Knowledge to successfully solve new physical problems or address ne physical situations.

   ii) “Demonstrated ability to deconstruct a physical system into its essential underlying principles.”
      (1) Deconstruct a physical system into its essential underlying principles.

   iii) “Demonstrated ability to undertake, manage, and oversee scientific research projects: develop hypotheses, design lines of inquiry, perform/execute/test, evaluate and iterate process as required.”

(1) Undertake, manage, and oversee scientific research projects: develop hypotheses, design lines of inquiry, perform/execute/test, evaluate and iterate process as required.

iv) "Demonstrated facility with core analytical, numerical/computational, and experimental techniques."
   (1) Apply core analytical, numerical/computational, and experimental techniques to analyze and investigate a physical problem or physical situation.

v) "Demonstrated ability to search, read, and understand scientific literature and apply understanding to new physical problems."
   (1) Search, read, and understand scientific literature and apply understanding to new physical problems.

4. Communication:
   i) "Demonstrated ability to explain and present ideas effectively to different groups of people (scientific and non-scientific audiences) in multiple formats (written, oral, graphical, symbolic)."
      (1) Explain and present ideas effectively to different groups of people (scientific and non-scientific audiences) in multiple formats (written, oral, graphical, symbolic).

5. Self-directed Learning:
   i) "Practised in the evaluation of personal performance and has the opportunity to explore opportunities for the advancement of knowledge and skills."
      (1) Review and assess personal performance.
      (2) Plan and propose opportunities for the advancement of knowledge and skills.
      (3) Understand the methods of science and the creative endeavour involved in acquiring scientific knowledge.
      (4) Understand that current scientific knowledge is testable and contestable.

6. Collaboration:
   i) "Demonstrated ability to work effectively as a member and leader of teams, preferably in inter-disciplinary settings."
      (1) Work effectively as a member and leader of teams, preferably in inter-disciplinary settings.

   ii) "Understanding/recognition that team members bring a wide range of different skills, knowledge, and approaches to problem solving."
      (1) Understand and recognize that team members bring a wide range of different skills, knowledge, and approaches to problem solving.

iii) “Practised in (including awareness of and sensitivity to) team-member diversity, including (but not limited to) gender, race, ethnicity, religious beliefs, sexual orientation, socio-economic status, age, physical abilities, political beliefs, or other ideologies.”
   (1) Bring awareness to team-member diversity, including (but not limited to) gender, race, ethnicity, religious beliefs, sexual orientation, socio-economic status, age, physical abilities, political beliefs, or other ideologies.

7. Ethical Practice:
   i) “Exposure to and practiced in, the understanding of the scope of ethical principles in the chose discipline.”
      (1) Understand the scope of ethical principles in the chose discipline.

   ii) “Exposure to and practiced in, the understanding of ethical and professional scientific practice and of standards in scientific integrity.”
      (1) Demonstrate knowledge of ethical and professional scientific practice and of standards in scientific integrity.

   iii) “Stated commitment to ethical, accountable, and equitable practice in all scientific and related endeavours.”
      (1) Recognize and accept ethical, accountable, and equitable practice in all scientific and related endeavours.

   iv) “Stated commitment to contributing one’s knowledge, skills, and expertise to both the profession and the community at large.”
      (1) Recognize and commit to contribute one’s knowledge, skills, and expertise to benefit and promote both the profession and the community at large.

   v) “Exposure to and practised in the ability to analyze social and environmental aspects of activities in the chose field of study, including an understanding of the interactions with the economic, social, health, safety, legal, and cultural aspects of society, and the concepts of sustainable design and development and environmental stewardship.”
      (1) Analyze social and environmental aspects of activities in the chose field of study.
      (2) Understand the interactions with the economic, social, health, safety, legal, and cultural aspects of society, and the concepts of sustainable design and development and environmental stewardship

Overview of Undergrad Programs in the Department of Physics and Astronomy

The Department of Physics and Astronomy offers two main undergraduate programs: a B.Sc. in Physics, and a B.Sc. in Astrophysics. Both are offered in a majors and honours stream, with the main difference being the minimum number of core courses that need to be taken over the course of study: 20-half courses in the case of majors, and 24-half courses in the case of honours. A minor in either physics or astrophysics can also be done.

The suggested course sequence for the major, honours, and minor programs in physics are shown in the table below. Of course, there is flexibility in this sequence. Also, not all students start their undergraduate studies in the Department of Physics and Astronomy, but the first year is similar for all students enrolled in a science program.

Some of the notable features of this program are the large number of mathematics, computer, and experimental courses, in addition to the core physics courses. The idea is to give students as many skills as possible that they might need in the job market upon graduation.

The key feature of our programs is the strong focus on learning computer, laboratory, and research techniques in addition to all the key physics and math concepts. The timing and content of physics (PHYS) and astrophysics (ASPH) courses are carefully chosen in order to integrate and scaffold the information across the years. The programs include a three-course sequence in computational physics (PHYS 381, 481, and 581), as well as a multi-year applied laboratory course (PHYS 397, 497, and 597) on top of the regular lab work associated with theory courses. These help students gain valuable laboratory and computational techniques and critical thinking skills necessary for their future careers. Students in their senior year must also complete a senior thesis course (the one-term PHYS 599 course for majors, or the two-term PHYS 598 course for honours students), in order to provide them with a first opportunity to conduct independent scientific research and to hone their oral and written presentation skills.

It is important to note that this Curriculum Mapping document only addresses core courses in PHAS undergraduate programs, and does not include service courses offered by the Department of Physics and Astronomy for students enrolled in other degree programs, nor does it address science and non-science options that students may take. For example, PHYS 211/221, 223, 321, and 323 correspond to a course sequence for students in other Science degree programs; likewise PHYS 259, 365, and 369 are service courses for the Faculty of Engineering. PHAS graduate courses are also not covered in this Curriculum Mapping.

Physics Curriculum (suggested):

(a) Major Program	
FIRST YEAR	
Fall	**Winter**
PHYS 227 (Classical Physics)	PHYS 255 (E&M I)
MATH 211 (Linear Algebra) **OR** MATH 213 (Honours Linear Algebra)	CPSC 217 (Intro to Computer Science)
MATH 275 (Calculus for Engineers and Scientists)	MATH 277 (Multivariable Calculus for Engineers and Scientists)
CHEM 201 (General Chemistry I)	CHEM 203 (General Chemistry II) **OR** BIOL 241 (Energy Flow in Biological Systems) **OR** BIOL 243 (DNA, Inheritance and Evolution) **OR** ASPH 213 (Intro to Astrophysics)
Non-science option	Non-science option
SECOND YEAR	
PHYS 341 (Classical Mechanics I)	PHYS 343 (Classical Mechanics II)
PHYS 397 (Applied Laboratory I)	PHYS 381 (Computational Physics I)
MATH 311 (Linear Methods II)	PHYS 325 (Modern Physics)
MATH 375 (Differential Equations for Engineers and Scientists)	MATH 377 (Vector Calculus for Engineers and Scientists)
PHYS 375 (Intro to Optics and Waves)	Non-science option
THIRD YEAR	
PHYS 449 (Statistical Mechanics I)	PHYS 443 (Quantum Mechanics I)

PHYS 455 (E&M II)	PHYS 457 (E&M III)
AMAT 433 (Mathematical Methods in Physics)	PHYS 497 (Applied Laboratory II)
Option	Option
Non-science option	Non-science option
FOURTH YEAR	
PHYS 599 (Research in Physics) **OR** PHYS 598 (Research in Physics I)	PHYS 501 (Special Relativity)
400- or 500-level Physics option	Non-science option
Science option	Science option
Option	Option
Non-science option	Non-science option

(b) Honours Program	
FIRST and SECOND YEARS Same as for the Physics Major Program	
THIRD YEAR	
PHYS 449 (Statistical Mechanics I)	PHYS 451 (Statistical Mechanics II)
PHYS 455 (E&M II)	PHYS 457 (E&M III)
PHYS 481 (Computational Physics II)	PHYS 497 (Applied Laboratory II)
AMAT 433 (Mathematical Methods in Physics)	PHYS 443 (Quantum Mechanics I)
Non-science option	Non-science option
FOURTH YEAR	
PHYS 543 (Quantum Mechanics II)	PHYS 501 (Special Relativity)

PHYS 597 (Applied Laboratory III)	PHYS 598 (Research in Physics II)
PHYS 598 (Research in Physics I)	Non-science option
Science option	Science option
Non-science option	Non-science option

(c) Minor in Physics
PHYS 211 or 221 or 227
PHYS 223 or 255
4.0 FCE at the 300-level or higher in the field of Physics
Mathematics prerequisites as needed

The suggested course sequence for students registered in the astrophysics major, honours, and minor curriculum are shown in the table below. This is much like the physics program, except that some physics courses are substitutes for various astrophysics courses.

Students thinking of entering into astrophysics are **strongly recommended to have taken Math30, Math 31 and Physics 30** in high school to avoid possible exclusion from certain courses.

Please be advised that ASPH 401, ASPH 409, ASPH 503 and ASPH 509 are offered alternate years. Students in astrophysics should take these courses the year they are taught or risk delaying their degree.

Astrophysics Curriculum (suggested):

(a) Major Program	
FIRST YEAR	
Fall	**Winter**
PHYS 227 (Classical Physics)	PHYS 255 (Electromagnetic Theory I)
MATH 211 (Linear Algebra) **OR** MATH 213 (Honours Linear Algebra)	CPSC 217 (Intro to Computer Science)
MATH 275 (Calculus for Engineers and Scientists)	MATH 277 (Multivariable Calculus for Engineers and Scientists)
CHEM 201 (General Chemistry) **OR** CHEM 209 (General Chemisty) **OR** CHEM 211(General Chemistry)	ASPH 213 (Intro to Astrophysics)
Non-science option	Non-science option
SECOND YEAR	
ASPH 307 (Intro to Oberservational Astrophysics)	PHYS 325 (Modern Physics)
PHYS 341 (Classical Mechanics I)	PHYS 343 (Classical Mechanics II)
MATH 311 (Linear Methods II) **OR** MATH313 (Honours Linear Algebra II)	PHYS 381 (Computational Physics I)
MATH 375 (Differential Equations for Engineers and Scientists)	MATH 377 (Vector Calculus for Engineers and Scientists)
PHYS 375 (Intro to Optics and Waves)	Non-science option

THIRD YEAR	
ASPH 401 (Galactic Astrophysics)[1] **OR** ASPH 503 (The Interstellar Medium)	ASPH 403 (Stellar Structure & Evolution)[1]
PHYS 449 (Statistical Mechanics I)	PHYS 443 (Quantum Mechanics I)
PHYS 455 (Electromagnetic Theory II)	ASPH 409 (Planetary Astrophysics) **OR** ASPH 509 (High Energy Astro and Cosmology)
AMAT 433 (Mathematical Methods in Physics)	Option
Non-science option	Non-science option
FOURTH YEAR	
ASPH 503 (The Interstellar Medium)[2] **OR** ASPH 401 (Galactic Astrophysics)	ASPH 509 (High Energy Astro & Cosmology)[2] **OR** ASPH 409 (Planetary Astrophysics)
400- or 500-level Physics option	400- or 500- level Physics option
Science option	Science option
Option	Option
Non-science option	Non-science option

(b) Honours Program	
FIRST and SECOND YEARS Same as for the Astrophysics Major Program	
THIRD YEAR	
ASPH 401 (Galactic Astrophysics)[1] **OR** ASPH 503 (Interstellar Medium)	ASPH 403 (Stellar Structure & Evolution)[1]
PHYS 449 (Statistical Mechanics I)	PHYS 451 (Statistical Mechanics II)
PHYS 455 (Electromagnetic Theory II)	PHYS 457 (Electromagnetic Theory III)
AMAT 433 (Mathematical Methods in	PHYS 443 (Quantum Mechanics I)

Physics)	
Non-science option	ASPH 409 (Planetary Astrophysics) **OR** ASPH 509 (High Energy Astro and Cosmology)
FOURTH YEAR	
ASPH 503 (The Interstellar Medium) **OR** ASPH 401 (Galactic Astrophysics)	PHYS 599 (Research in Physics)
PHYS 543 (Quantum Mechanics II)	ASPH 409 (Planetary Astrophysics) **OR** ASPH 509 (High Energy Astro and Cosmology)
Option	PHYS 501 (Relativity)
Science option	Non-science option
Non-science option	Non-science option

(c) Minor in Astrophysics
0.5 FCE - ASPH 213
2.5 FCE - Courses labelled Astrophysics
2.0 FCE - PHYS 227*, 255*, 325, 341*
0.5 FCE - MATH 211 or 213
1.5 FCE - MATH 275, 277, 375
0.5 FCE - CPSC 217
*The sequence PHYS 211 or 221, 223, 321 and 323 may be substituted for the sequence PHYS 227, 255 and 341.

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[1]*The semesters that ASPH 401 and ASPH 403 are offered change year to year, students can take these courses in whichever semester they are offered.*

[2]*Students must take one of ASPH 503 or ASPH 509. They cannot both be substituted by a 400- or 500-level physics option, and a minimum of two 400- or 500-level physics options must be taken.*

Students also have the opportunity to enroll in an interdisciplinary degree program with a strong physics component. These include:

- Environmental Science, administered jointly by the Faculties of Science and Social Science [Helen is this really true?]
- Natural Sciences, major, honours, B.Sc/B.Ed., or B.Sc/B.A. joint programs with physics as one of two concentrations.

Alignment with Priorities of the University of Calgary's Academic Plan

How does this review and your program align with the Eyes High Academic Plan?

The University of Calgary's 2012 Academic Plan is founded on three institutional commitments, guiding the Eyes High vision:

1) Sharpen the focus on research and scholarship;
2) Enrich the quality and breadth of learning;
3) Fully integrate the university with the community.

Our undergraduate programs fully align with these core principles, as discussed in detail below. Seven academic priorities were identified to guide the Eyes High goals: Teaching and Research Integration, Interdisciplinarity, Connection with the Community, Leadership, Talent Attraction Development and Retention, Sustainability, Internationalization. Our undergraduate programs address each of these:

- **Teaching and Research Integration**: During the first two years of the recommended PHAS course sequence, students perform laboratory experiments as a required component of their Physics courses. These hands-on experiments complement the theoretical content learned in the lecture sections, and teach students essential laboratory skills that are a first step toward performing real research. PHAS students take a scaffolded series of laboratory-skills courses (PHYS 397, 497, and 597). Students learn basic experimental methods (including data and error analysis), technical skills, and effective communication skills through their laboratory write-ups. This sequence culminates in a senior project-style laboratory course where students must independently assemble and test laboratory apparatus for the investigation of modern physical phenomena. Finally, all students in their senior year perform independent research under the supervision of a faculty member within physics and astronomy or a closely-related discipline, and write a senior thesis to accompany it (as well as present their results orally).
- **Interdisciplinarity**: All students in their first year of studies are required to take a computer science and chemistry course, and have the choice of an additional chemistry or biology course. This ensures a certain level of scientific breadth. Furthermore, all students in PHAS programs are required to take a series of courses in pure and applied mathematics, including courses in calculus, linear algebra, and mathematical physics. In addition to the recommended PHAS courses that make up the core of our students' B.Sc. degree, all students are required to take a minimum of six half-course equivalents in complementary studies ("non-science options" in the recommended course sequences shown in the previous section). This provides students with numerous opportunities to explore topics outside of their core discipline.
- **Connection with the Community**: The Department of Physics and Astronomy has an exceptional research and outreach facility, the Rothney Astrophysical Observatory. This

facility is an intrinsic resource for students in our Astrophysics course offerings, and also provides all members of our department with numerous opportunities to engage with the public during its many Open Houses. Undergraduate students help in the organization, give scientific presentations, and provide technical support for Open House telescope operations. Students have numerous opportunities to hear about exciting developments in PHAS and related areas during almost-weekly departmental colloquia and numerous scientific public lectures hosted by PHAS departmental members and institutes. Finally, all members of the department, including undergraduate students, present the results of their research at meetings, workshops, and conferences, as well as at occasional public events (such as Science Cafés, Science in the Cinema events, etc.).

- **Leadership**: Though the Department of Physics and Astronomy is the smallest in the Faculty of Science in terms of total numbers, departmental members are leaders in a number of respects. Our instructors are early and enthusiastic adopters and developers of teaching and learning technologies, such as classroom response systems, on-line demonstrations, and web-based approaches to marking exams and distributing grades to students, among others. Several of our Instructors (teaching professors) are deeply aware of the latest research on effective teaching and learning methodologies, including the extensive Physics Education literature, and are keen to apply the results in the classroom. The Department was the first in the Faculty to develop and fill the position of an Undergraduate Learning Coordinator, whose responsibility it is to coordinate all the large first-year and second-year PHAS service courses, help develop the undergraduate laboratories, and to train teaching and learning assistants. PHAS spearheaded a novel opportunity for graduate students to teach PHAS courses, the Graduate Student Record of Instruction program; this has now run for two years and has been quite successful, both in the training of our future educators and in the quality of course instruction. PHAS programs were the first in the Faculty of Science to require all undergraduate students to undertake an independent research project. Many of our faculty members are world leaders in their areas of research, and this elevates the quality of our undergraduate research. Several of our emeritus faculty members have written undergraduate textbooks in astronomy, for example Eugene Milone and Bill Wilson's "Solar System Astrophysics" (two volumes) and Eugene Milone and David Kelley's "Exploring Ancient Skies."
- **Talent Attraction Development and Retention**: PHAS program offerings are clearly of interest to incoming students, as we consistently attract a healthy cohort of high-quality undergraduate students. Some of this interest can be attributed to our excellence in teaching; our instructors regularly win University and Student Union teaching awards. Over the past two years we have attracted two Instructor-stream faculty members, both of which are committed to evidence-based teaching practices. That said, as can be seen in the data (discussed in detail below), our retention throughout the program is not as strong as we would like it to be, with an average factor of 2.7 loss in student numbers from first to senior years. That said, this attrition rate is consistent with STEM attrition rates in the U.S., where data are available.

- **Sustainability**: The Department of Physics and Astronomy is an unsung leader in sustainability. All of the computers in our undergraduate computer labs are re-purposed machines that are surplused from other departments and faculties (particularly Computer Science and Engineering). Whenever possible, laboratory equipment is repaired by laboratory technical personnel. Laboratory manuals and equipment are regularly reviewed, renewed, and developed by a team of departmental members including faculty, staff, technical personnel, and students.
- **Internationalization**: The Department of Physics and Astronomy and the Faculty of Science intend to strongly ramp up the proportion of international students through an aggressive internationalization plan. For example, the Department is exploring several joint degree programs with foreign universities; these so-called 2+2 and 3+2 programs allow students to obtain degrees both from the UofC and their home institution. Students in our laboratories are trained and supervised by a large team of graduate students, the majority of whom are not Canadian nationals. The Department also has several exchange programs in place that allow students to study abroad and apply their foreign coursework to their PHAS degree requirements, and vice versa. That said, the data presented in this document show that while undergraduate students in PHAS programs are diverse in terms of ethnicity, ideology, etc., the majority hail from Calgary and its environs; the Department therefore needs to aggressively pursue other avenues for attracting the best and brightest students to our program offerings.

The 2012 Academic Plan lists 29 Goals for achieving its Eyes High vision, each with its attendant strategies. Here, for brevity, we explicitly address a small subset of these, relating to undergraduate teaching and learning.

- **Goal 1: Attract, develop and retain talented students.**

  <u>Strategy 1.8: Ensure a positive teaching and learning environment on campus:</u>

  Evaluate and analyze the study spaces on campus. Develop a plan with the students to enhance spaces that are currently under-used, and to create further types of study spaces where required (2011-12 and ongoing).

  Initiate, implement and provide central resources to university-wide classroom and facility alteration programs to ensure best use of available resources (2011-12). This program will be enhanced by developing and implementing a university-wide strategic plan for instructional space and improvement that includes a discussion of space standards (2012-13).

  PHAS courses are frequently taught in state-of-the-art lecture halls with Smart podiums, advanced lighting and audio-visual equipment. Some of the rooms provide movable chairs and desks as well as interactive displays, to enhance in-class participatory learning approaches. In addition to modern equipment, our experimental laboratories feature movable carts with computers for data visualization and analysis, as well as allowing for interactive simulations and web-based experiments. Outside of class time, students can meet to collaborate on projects and assigned work in a variety of useful spaces. These include a dedicated classroom surrounded by whiteboards, a computational physics laboratory with 44 computers, and the senior laboratory space. The undergraduate Physics and Astronomy Physics Association (PASA) has dedicated space for social and work activities. There are also various congregation spaces in the vicinity of the Departmental Offices for undergraduates to mingle with faculty members, departmental staff, graduate students, and postdoctoral fellows, among others.

Develop strategies to increase and measure the quality of teaching on campus (2012-13 and ongoing).

PHAS programs have strongly benefitted in recent years by strong initiatives pursued both by the Faculty of Science and the Taylor Institute for Teaching and Learning, to encourage instructors to apply innovative and evidence-based teaching methods in our course offerings. Our instructors have attended numerous workshops, courses, and longer-term programs (for example the Teaching Squares and C-LAB programs which are joint initiatives of the FoS and TITL). Our graduate students are trained weekly by department personnel (in particular the new Undergraduate Learning Coordinator), and our Graduate Student Instructors of Record are trained by faculty members and the ULC prior to embarking on teaching, and are regularly monitored and supported by instructors throughout the term. The quality of instruction is measured by a range of instruments, including student USRI scores, in-class observations, and student comments. Indeed, salary increments for faculty members that are recommended by the Department Head are partially tied to the inferred quality of teaching.

Nominate and promote deserving undergraduate and graduate students for national and international awards and recognition (2012-13 and ongoing).

Each year, the Department gives prizes to the highest-achieving undergraduate students in our programs, and hosts a celebratory luncheon for them.

Develop and implement a strategic plan for information and communication technologies (ICT) to enrich the existing on-campus and distance education experiences. This strategic 2012 Academic Plan will include a plan for upgrading the information technology backbone throughout the institution, and will include how we incorporate virtual worlds to integrate teaching and research in the student experience, including topics such as simulation platforms, social media, and learning management systems. The ICT and learning plan will explore the use of new and emerging technologies in undergraduate and graduate research for the development and testing of new ideas (begin in 2011-12, with completion by 2015-16, followed by on-going maintenance of infrastructure).

PHAS programs are strongly supported by the University's ICT infrastructure. Students in their first and second years are required to complete on-line homework assignments, perform web-based research, and participate in electronic interactive simulations and experiments. All courses are hosted on the University's learning management system Desire to Learn (D2L), and many PHAS courses employ TopHat for in-class discussions and evaluations. In later years, students use centrally hosted software packages, such as Mathematica, Maple, and Matlab, as well as perform simulations over multiple computers in the Computational Laboratory.

- **GOAL 6: Create support and incentives for academic staff to develop their teaching expertise**

<u>Strategy 6.1: Senior academic administration commit to valuing and supporting teaching and learning excellence on campus</u>

Define, support and reward teaching and supervision excellence (begin in 2011-12 and ongoing).

Support and enable the development of expert teaching practices through reallocation of budget and other resources (2012-13 and ongoing).

Integrate structures and resources within Faculties and schools and across campus to support the development of expert teaching practices (2012-13 and ongoing).

<u>Strategy 6.2: Academic staff commit to creating an intellectually engaging learning environment for all students</u>

Assist students to develop expertise and leadership in their chosen fields (2011-12 and ongoing).

Use research-informed teaching and learning supervision practices (2012-13 and ongoing).

Develop teaching expertise through ongoing professional development activities (2012-13 and ongoing).

PHAS programs have strongly benefitted in recent years by strong initiatives pursued both by the Faculty of Science and the Taylor Institute for Teaching and Learning, to encourage instructors to apply innovative and evidence-based teaching methods in our course offerings. Our instructors have attended numerous workshops, courses, and longer-term programs (for example the Teaching Squares and C-LAB programs which are joint initiatives of the FoS and TITL). Our graduate students are trained weekly by department personnel (in particular the new Undergraduate Learning Coordinator), and our Graduate Student Instructors of Record are subjected to training by faculty members and the ULC prior to embarking on teaching, and are regularly monitored and supported by instructors throughout the term. The quality of instruction is measured by a range of instruments, including student USRI scores, in-class observations, and student comments. Indeed, salary increments for faculty members that are recommended by the Department Head are partially tied to the inferred quality of teaching.

- **Goal 8: Develop and implement a comprehensive system of course, program, and teaching effectiveness evaluations to support ongoing improvement of teaching and learning**

  Strategy 8.1: Make evidence based decisions on teaching and learning policy and practice

  Collect and use data on teaching and research to inform teaching and supervision practices, program development and program quality (2012 and ongoing).

  Develop and implement policies and processes to support, guide and evaluate teaching and research supervision expertise (2012-13).

  Support all academic staff to develop research-informed teaching and supervision practices (2012-13).

  Ensure assessment practices to support and guide teaching and research supervision are relevant to the specific culture of a discipline (2013-14 and ongoing).

  As discussed above, the Faculty of Science and the Taylor Institute for Teaching and Learning have been strongly supporting initiatives to inform instructors of new and evidence-based teaching practices. In terms of program quality, this Course Mapping Report is an excellent example of the University of Calgary and the Faculty of Science proactively engaging with departments to evaluate the integration of course offerings across and among programs. While the Department of Physics and Astronomy began such an undertaking in recent years, this initiative has ensured that we are doubling down on the effort.

  Develop explicit student outcome goals and knowledge attributes for all undergraduate and graduate programs (2013-14 and ongoing).

  Two years ago, at the Faculty of Science's initiative and using the Faculty's template as a springboard, the Department undertook a process to define its program outcome goals. These are given explicitly in the Program Outcomes Section above, and have been officially adopted by the Department.

  Strategy 8.2: Collect and use a variety of data to support, assess, evaluate and improve teaching and graduate supervision effectiveness.

Apply merit, promotion, and tenure guidelines consistently that emphasize the importance and value of effective teaching and student supervision (2012 and ongoing).

The quality of instruction and undergraduate student supervision is measured by a range of instruments, including student USRI scores, in-class observations, and student comments. Salary increments for faculty members that are recommended by the Department Head are partially tied to the inferred quality of teaching and supervision.

Extend evaluation of teaching to include evidence of engagement in reflective practice (2013-14) and teaching professional development activities (2014-15).

Evidence of teaching development activities has long been a category to address when instructors complete their annual (or biennial) reviews.

The 2014 Strategic Framework for Learning Technologies identified five priority areas to enable the UofC to become a leader in teaching and learning. These are accompanied by 14 strategies to meet these priorities. These are the most relevant for our programs:

- **Priority 2: Learning Spaces**: Our physical spaces and digital platforms must be adaptable, accessible, and designed to be secure and reliable environments for high-quality learning.

  Strategy 4. Provide high-quality, flexible spaces for formal and informal learning experiences.

  Many courses that are required for a B.Sc. in Physics or Astrophysics have both lecture and a laboratory components, with their own dedicated spaces. First-year courses might contain as many as 100 students in a lecture, with 20-50 students in fourth-year courses. Thus, the lecture components can usually take place in standard classrooms with movable desks and chairs, facilitating a variety of teaching styles and in-class learning modalities. The Department has invested in a series of dedicated laboratory spaces to support experiment-driven learning. These include the junior and senior laboratories as well as the computational physics laboratory. These are run by a strong team of laboratory personnel, in close collaboration with departmental stakeholders including instructors, departmental staff, the undergraduate learning coordinator, graduate student teaching assistants, and undergraduate learning assistants, among others. These labs contain state-of-the-art equipment that is maintained by a technical team. The computational physics laboratory was completely renovated and renewed last year. In November 2016, the Department was awarded funds from the Faculty of Science to invest in new equipment to develop a suite of new laboratories spanning our physics and astrophysics offerings.

In addition to these formal learning spaces, the Department has two spaces for informal learning and coursework. When the computational physics laboratory is not being used during class time for the Computational Physics sequence of courses (PHYS 381, 481, and 581), this space and all 44 computers are accessible to students. Unsurprisingly, this space is a focal point for students to continue their studies outside of class, to work on assigned problems and term projects, and to have discussions. In addition, the Department has a dedicated classroom physically situated across from the computational physics laboratory for informal learning. This has many movable desks and chairs, and all four walls are covered in whiteboards to allow students to do calculations in groups. At least one day a week, this room is dedicated to holding office hours for teams of instructors, and often PHAS students join in helping students in PHAS service courses with their problems.

The Taylor Institute for Teaching and Learning (TITL) has dedicated learning spaces for selected courses (two competitions are held annually) with state-of-the-art technical equipment and flexible furniture; in Winter 2017 the general-interest course PHYS 271 (How Things Work) will be offered in one of these spaces.

<u>Strategy 5. Develop and support robust, reliable, and sustainable platforms for technology-enhanced learning.</u>

The university has invested in smart podiums for most classrooms, which enhances course delivery in the lecture portion of the courses. The university has purchased a site license for TopHat, the in-class ‘clicker’ system, which is an excellent technologically-driven way to engage students in the classroom as well as for instructors to gauge their understanding. Courses are all hosted on Desire to Learn (D2L), which facilitates the management of courses, the marking and distribution of grades, and the storage and accessibility of course materials. The university also has site licenses for many important software packages that are used by PHAS students throughout their courses, including the full Microsoft Office and Adobe suites; the symbolic and numeric packages Maple, Mathematica, and MATLAB. The university has centralized media services for the printing and scanning of exams and coursework.

Priority 3: Supportive Environment: We must support the work of students, faculty, and staff in every discipline to integrate learning technologies while respecting the time commitments of all stakeholders.

<u>Strategy 6. Provide mentoring, coaching, and training to students, faculty, and staff.</u>

The Faculty of Science offers strong technical support for learning activities, by financially supporting graduate students who can be technical resources for instructors and departmental staff, by developing software to aid in course delivery (for example the AMPS package developed for distributing the grades from multiple-choice exams to D2L), and by supporting a team of technical and academic advisors to the departments.

Leaders in the TITL and the Faculty of Science, as well as instructors across the Faculty, regularly hold meetings on effective teaching practices, from one-hour talks, longer workshops, to week-long courses. The Department is committed to quality instruction; course ratings and evidence of successful classroom practice is a core component in the allocation of merit salary increases by the Department Head. In addition, the Department supports innovative classroom practices by allocating graduate-student teaching assistantships for inquiry-based classroom activities.

Strategy 7. Build learning technology capacity to support discipline-specific pedagogies.

Until the recent retirement of one of the Department's technical personnel, we were able to offer a system for on-line grading and distribution of exams that was unique at the University. All exams (particularly those for our large first-year courses) would be scanned, distributed to teaching assistants for marking, and then digitally distributed to students on D2L. In this way, students not only obtained their grades but also could see where they made mistakes on the short and long-answer portions of their exams. Unfortunately, the retirement now precludes our ability to scan the exams, which in practice limits questions to multiple choice. This does not offer our students the same pedagogical value, unfortunately. Thankfully, the new provider of printing and scanning services on campus, West Canadian Digital Imaging, has offered to look into providing these essential scanning services in the near future. Technical, academic, and management personnel in the Faculty of Science are interfacing with us on this initiative.

The Department is constantly developing new laboratories for the successful implementation of experiential learning in PHAS courses. Each year, entire suites of laboratories are either totally revamped or are further developed. In this way, the Department strives to ensure that the learning in our laboratories remains at the highest quality.

Data Sources Used

The analysis presented in this document are based on a variety of data sources, which are included in Appendices I through VI. These include:

- The Curriculum Mapping Data, Appendix I, which was collected by the Faculty of Science on behalf of the Department of Physics and Astronomy;
- Data and comments from the Physics and Astronomy Undergraduate Student Survey, Appendix II, which has been collected yearly from 2013 through 2016;
- Data and comments from the Alumni Student Survey, collected on behalf of the Department of Physics and Astronomy by the Faculty of Science;
- Student and Course data, collected by the Consortium for Student Retention Data Exchange, of which the University of Calgary is a member;
- Survey data from the 2014 National Survey of Student Engagement.

Analysis of the Curriculum Mapping Data (Appendix I)

In this section we analyze the curriculum mapping data.

Section 1: All Courses in PHAS Program and Depth of Program Learning Outcomes (PLO)

Technical Outcomes:
Knowledge of Concepts and Theories
Critical Thinking
Research & Problem Solving

There is a clear evolution from D (Developing) to A (Advanced) from 200-level to 500-level courses, with a clear demarcation between 400-level and 500-level courses. That said, it is interesting that most instructors did not consistently choose I (Introduced) for courses where topics are first introduced; these include ASPH 213 (D,I,0), PHYS 227 (D,D,D), PHYS 303 (D,D,I), PHYS 325 (I,D,D), PHYS 375 (A,D,D), PHYS 381 (I,D,D), PHYS 397 (D,I,D), and PHYS 449 (D,D,D). This speaks to an assumption among instructors for each course that students have had some opportunities to address these learning outcomes in previous courses. Exceptions are PHYS 255 (I,I,I), PHYS 271 (I,I,I), and PHYS 371 (I,I,0). Also remarkable is that the main classical mechanics sequence (PHYS 341 and 343) is viewed by the instructor as (A,A,A) in these categories, despite their being second and third courses on this topic; one might have expected PHYS 341 to be classified as (D,D,D). After these data were presented to PHAS instructors, it was revealed that there was broad confusion about how to interpret the I,D, and A designations; in particular, if the letter represented students' understandings by the end of the course, or the level at which the material was pitched to the student. This misunderstanding likely contributed to some of the observed mismatches in the smooth progressions from early to senior courses.

Broad-Learning Outcomes:
Communication
Self-directed Learning
Collaboration

In these categories there is again a trend from I to A, but the trend is not as strong nor the transition from D to A as clearly demarcated as they were for the technical outcomes. In several instances instructors designated one or several D assessments for early courses (PHYS 271, ASPH 307, PHYS 303, and PHYS 375) while I assessments pop up in later courses (PHYS 451, PHYS 455, PHYS 497, ASPH 503, ASPH 509, and PHYS 561). This is most pronounced for the Collaboration outcome; indeed, the lack of opportunities for students to collaborate has been a consistent comment in our Undergraduate Student Evaluations (see below).

Ethical Understanding:

The assessment for this category is almost uniformly I, for courses where it was identified as a learning outcome at all. Notable exceptions are PHYS 599 and PHYS 598, which are the senior and honours thesis courses, respectively. In these courses students are exposed to ethical practice in scientific research as well as exposed to understandings about originality in written and oral communications.

Section 2: Individual Course Maps for the Physics and Astronomy Program

The tables contained in the subsection "Individual Course Maps for the Physics and Astronomy Program" fine-grain the aggregate data presented in the previous table. Here only notable features beyond those mentioned above will be discussed.

PHYS 303: While most learning outcome categories are assessed at an I level, the course-level learning outcome "Make predictions for simple quantum thought experiments using the concepts of interference and the indistinguishability principle" is designated as D for all program-level outcomes. This in spite of the fact that this is a general-interest course for non-scientists on the ideas of quantum mechanics.

PHYS 325 and PHYS 397: In addition to technical course-level outcomes, Collaboration and Communication are both included in these courses, with assessments at the I and D levels. Thus, our second-year students have opportunities to collaborate in group work as well as a first opportunity to communicate their results. In PHYS 397 these communications are in the form of laboratory write-ups, while in PHYS 325 students traditionally present the results of their experiments in a poster session.

PHYS 341: Almost all technical and broad-learning outcomes (Communication and Self-directed Learning only) are assessed at A. This is remarkable as this is only the second course in Mechanics that PHAS students take, and they are still in the process of completing their mathematics training (MATH 375 runs simultaneously, and MATH 377 and 311 are taken the following semester). This course is widely perceived as a 'weeding-out' course for PHAS students, who find the technical aspects of the material to be a challenge.

PHYS 343: This the third course of the PHAS Classical Mechanics sequence. It is notable that while Communication and Self-directed Learning were assessed at the A level, for the net course in the series all but one of the broad-learning categories Communication, Self-directed Learning, and Collaboration are assessed as D. The results for PHYS 341 and 343 suggest that a closer look at the course expectations and outcomes is in order.

PHYS 371: Though many program-level outcomes are not included in the course outcomes, it is notable that Ethical Understanding is included at the I and D levels.

PHYS 375: While technical outcomes are assessed as A,A,D, the broad-learning outcomes are I,I,D. Considering that this is a first course in Optics for students in PHAS programs, these assessments strongly indicate a presumption of technical expertise on the part of students. Likewise, students are expected to collaborate with one another on their work at a developed level, in spite of their having had (thus far in their programs) somewhat limited opportunities for this.

The Department is currently debating the merits of offering this first course in Optics and Waves as a second-year course. Historically, this was a senior-year course (PHYS 575), but a decision was made several years ago to offer it earlier, under the expectation that it could be taught effectively at a level that required a less sophisticated background; this gave students the technical background to enable them to work in the world-renowned quantum optics and atomic, molecular, and optical physics experimental groups housed within PHAS. The Department intends to scrutinize the issue further in the near future.

PHYS 381: Both technical and broad-learning outcomes are assessed at I and D, with the majority at D. Interestingly, while this is a second course in using computers for scientific investigation (the first is a service course for science students offered by the Department of Computer Science), the Knowledge of Concepts and Theories and Self-directed Learning categories are assessed as I. This suggests that students are perceived to not be sufficiently exposed to these opportunities in their first computer science course.

PHYS 449 and 451: Almost all course learning outcomes are technical; yet for Collaboration and Ethical Understanding there is an I assessment for both courses, associated with students' displaying their understanding in oral and written form.

PHYS 457: Though this is a third course in Electromagnetic Theory, with D and A assessments in the Research & Problem Solving category, the overall assessment for this learning outcome is assessed to be I. Consultation with the instructor, Brian Jackel, indicates that is likely a typographical error, and should have been designated a D.

PHYS 481: The second course in the computational physics sequence is assessed as D,D,I in all technical categories, and as A,I,I in the broad-learning categories. Thus, problem solving is seen as introductory, while Communication is seen as advanced while Self-directed Learning and Collaboration are both considered introductory.

PHYS 497: Though the technical learning outcomes generally rate a D, the course-level outcomes touch on the program-level broad-learning outcomes of Communication and Self-directed Learning, with mostly I but some D assessments; The D ratings correspond to self-directed abilities with technical apparatus.

ASTR 213: This first course in Astronomy has no course-level broad-learning outcomes, as might be expected for a large first-year service course.

ASPH 307: As the second course in Astronomy (though the first in Astrophysics), one might expect to find many D evaluations. This is indeed the case, for all program-level outcomes save Ethical Understanding (which is rated I). This indicates that students are exposed to a range of broad learning even at the second-year level.

ASPH 401, 503, and 509: Though the overall evaluations leans toward D and A for these courses, the course-level outcomes for these courses are assessed to match the program-level learning outcomes evenly for I and D (ASPH 401) and across I through A (ASPH 503 and 509), for technical and for broad-learning outcomes (ASPH 503 and 509 only). This suggests that, though these courses are at the third and fourth-year levels, they are not perceived as intermediate or advanced courses in the context of programmatic scaffolding. Indeed, due to resource issues PHAS is not able to offer all ASPH courses each year; scaffolding of the information is therefore not as simple as for PHYS courses.

Section 3: Faculty of Science Graduate Attributes by Individual Course in PHAS Program

As the Faculty of Science Graduate Attributes inspired and informed the PHAS program-level learning outcomes, the outcomes closely follow those discussed above. Explicitly different outcomes include Science in Society, Creativity and Curiosity, Career Skills, Sustainability, and Social Responsibility, though these are largely included in the more fine-grained version of the program-level learning outcomes described above. First we summarize the courses that touch on these five learning outcomes:

Science In Society: PHYS 271, 303, 325, 371, 375, 443, 449, 507, 561, 598, 599; ASPH 509
Creativity and Curiosity: PHYS 255, 271, 303, 341, 343, 375, 381, 449, 451, 497, 507, 543, 581, 597, 509, 561, 598, 599; ASPH 307, 403, 509
Career Skills: PHYS 227, 255, 271, 303, 325, 341, 343, 371, 381, 443, 449, 451, 455, 481, 497, 501, 507, 561, 581, 597, 598, 599; ASPH 307, 403, 509
Sustainability: PHYS 303, 371; ASPH 509
Social Responsibility: PHYS 303, 371; ASPH 509

It is clear that for the majority of PHAS courses, the instructors believed that Creativity and Curiosity and Career Skills were integral to the learning. While some courses explored the broader aspects of science in society, very few currently discuss issues around sustainability or social responsibility. Major exceptions to this general observation are the three public-interest courses offered by the department: PHYS 271, 303, and 371. The data for the total number of course learning outcomes overlapping with those of the Faculty of Science are shown in Figure 1. The results are consistent with the preceding observations and with the comments surrounding the dovetailing of the course-level and program-level outcomes, above.

Given that Social Responsibility is a component of the Ethical Practice Program-level outcome for PHAS, the absence of these course-level learning outcomes across our program offerings is cause for concern. Outcome 7v of the PHAS Program Outcomes corresponds to: "Exposure to and practised in the ability to analyze social and environmental aspects of activities in the chose field of study, including an understanding of the interactions with the economic, social, health, safety, legal, and cultural aspects of society, and the concepts of sustainable design and development and environmental stewardship. (1) Analyze social and environmental aspects of activities in the chose [sic] field of study. (2) Understand the interactions with the economic, social, health, safety, legal, and cultural aspects of society, and the concepts of sustainable design and development and environmental stewardship." The 2014 NSSE data (Appendix V) further reinforce this observation. To the question "During the current school year, how often have you connected your learning to societal problems or issues?" the overwhelming majority of students responded with "Never" and "Sometimes." This Course Mapping exercise has helped to expose this deficiency in our current offerings, and is a matter of concern for future study.

The table "Research Activities Incorporated in Courses across PHAS Program" shows that for most PHAS courses, research is incorporated in a traditional way for the discipline: discussed in class (current or historical research) and/or performed as part of mandatory laboratory work (where applicable). That said, for a significant number of courses, research was incorporated in a number of different ways, spanning almost all suggested approaches; these include PHYS 271, 381, 397, 481, 561, 581, and 597, as well asd ASPH 307, 403, and 503. This speaks to the creativity of PHAS instructors and their willingness to engage in innovative teaching practices.

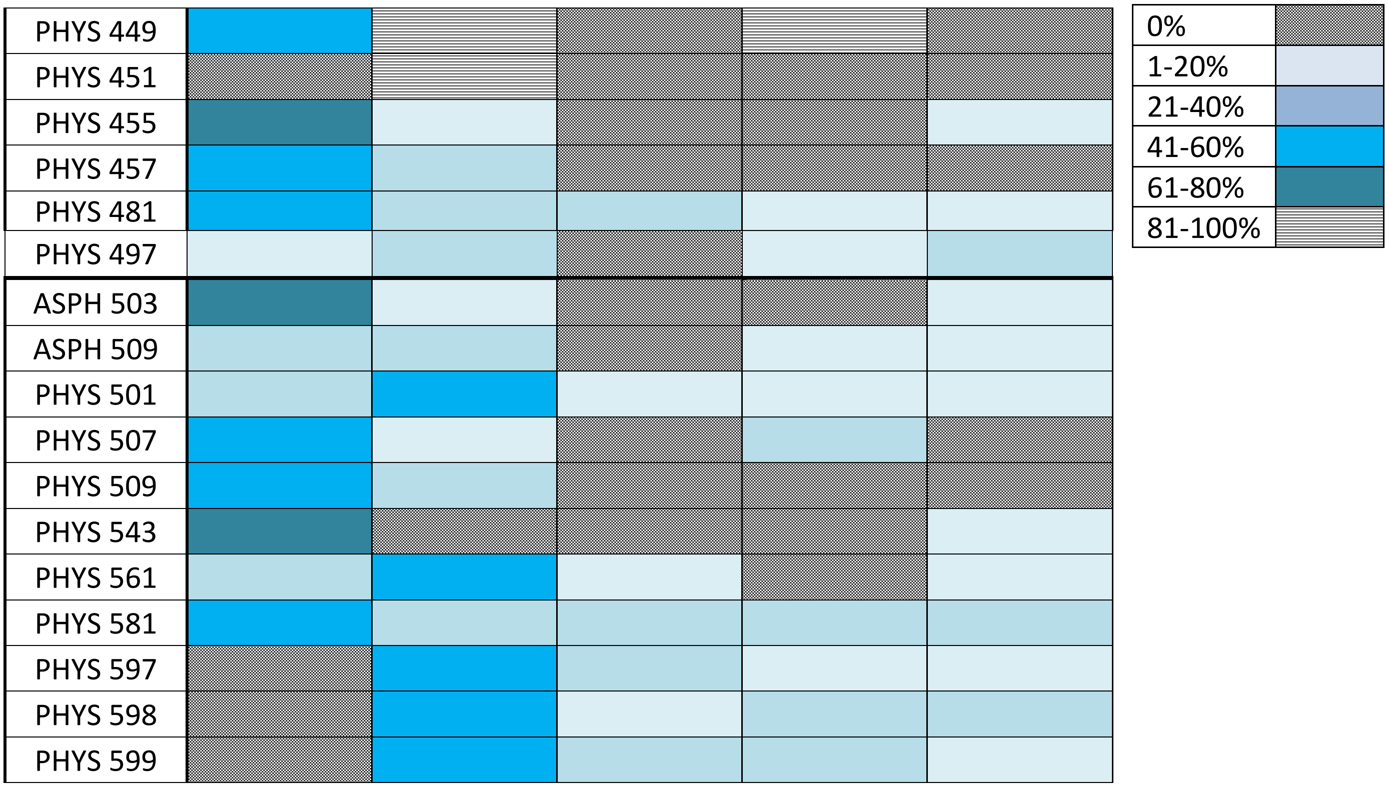
Section 4: Teaching and Learning Activities Across Courses

Figure 2 of this subsection shows the breakdown among courses of Teaching and Learning Activities carried out in class, with an estimate of time devoted to each activity. These include Direct Instruction, Interactive Instruction, Independent Learning, and Experiential Learning. As might be expected, most courses are weighted more heavily toward direct instruction, which corresponds to a more traditional (lecture-style) approach to teaching. The classroom time devoted to this teaching style generally increases from second-year to third-year offerings, where it peaks. Most of the third-year courses are core to the programs and are heavy on theory; these include the Statistical Mechanics, Electromagnetism, and Quantum Mechanics sequences. Note of these courses have laboratories associated with them, and all are expected to cover a large volume of technical material. Most instructors opt to cover this material in a traditional way. The time devoted to direct instruction drops off for most 500-level courses; these include the applied computational and experimental courses PHYS 581 and 597, respectively, and the senior thesis courses PHYS 599 and 598.

That said, many PHAS courses devote a significant amount of time to content delivery outside the Direct Instruction mode. These include courses that contain mandatory laboratories and tutorials (which are often run by graduate student TAs), of course. But there are several other examples as well, notably PHYS 227, 271, 375, 501, and 543, as well as ASPH 307 and 509; in all these cases, teaching methods are close to evenly distributed among Direct Instruction, Interactive Instruction, Independent Learning, and Experiential Learning. This speaks to innovative approaches to teaching at all levels of our course offerings. For example, in the case of ASPH 307 heavy use is made of the Rothney Astrophysical Observatory; for PHYS 227, worksheets and clicker questions are heavily employed; for PHYS 271, the course is given in a 'flipped classroom' style, where students study at home and perform activities during class time. Furthermore, the experimental and computational course sequences (PHYS 397, 497, 597, and PHYS 381, 481, and 581, respectively) are highly self-directed and experiential in nature; likewise, the senior thesis courses (PHYs 599 and 598) are entirely research based.

Figure 4: A breakdown of the utilization of the different types of student assessments by course (Exams, Written Assessment, Oral Assessment, Skills Assessment and Participation/Engagement) across the Physics and Astronomy Program. Respondents were asked: “When assessing students in this course, approximately what percent of term score is determined by these methods. (Does not have to add up to 100%)” Data extracted from the PHAS course mapping survey.

COURSE No.	Exams	Written Assessment	Oral Assessment	Skills Assessment	Participation/ Engagement
ASPH 213					
PHYS 227					
PHYS 255					
PHYS 271					
ASPH 307					
PHYS 303					
PHYS 325					
PHYS 341					
PHYS 343					
PHYS 371					
PHYS 375					
PHYS 381					
PHYS 397					
ASPH 401					
ASPH 403					
PHYS 443					
PHYS 445					



If you use an assessment method not listed above, please provide more information:

ASPH	213	Homework assignments do not seem to fit in these categories. I included them under "exams". TopHat Monocle does not seem to fit anywhere. It is used to give feedback in a low-stakes environment.
ASPH	307	FYI, I include assignment work in the Written Assessment category - and this is done outside of class time usually in collaboration with peers.
ASPH	401	Not sure how to list homework assignments in this course. They are included here under "other" in :exams". The last three categories do not apply.
ASPH	503	Home work assignments (individual). Assignment 1 required students to take a picture of a cloud, recording necessary data, and analyze light scattering by the chosen cloud. Other assignments included more traditional problems and interpretation of data.
PHYS	271	Weekly assigned problems (delivered and graded on-line); it's weird that this isn't listed
PHYS	371	I put the homework on an electronic learning platform within D2L.
PHYS	543	Homework

Figure 4 shows the utilization of various student assessment methods: Exams, Written Assessment, Oral Assessment, Skills Assessment and Participation/Engagement. Most PHAS courses make heavy use of exams as an assessment tool, as is expected. Intriguingly, the vast majority of courses employ written assessment, making up 1-60% of the total grade. This speaks to the attention paid by PHAS instructors to the "Writing Across the Curriculum" goal expressly noted in the University Calendar: "Writing skills are not exclusive to English courses and, in fact, should cross all disciplines. The University supports the belief that throughout their University careers, students should be taught how to write well so that when they graduate their writing abilities will be far above the minimal standards required at entrance. Consistent with this belief, students are expected to do a substantial amount of writing in their University courses and, where appropriate, members of faculty can and should use writing and the grading thereof as a factor in the evaluation of student work." This observation is further validated by the data presented in Figure 5, where 79% of respondents provided students with opportunities for oral and written communication in their courses.

The comments below Table 4 elaborate on the approaches various instructors take toward assessment. Many courses stress the importance of homework assignments; these not only test technical knowledge, but also provide students with numerous opportunities to express themselves verbally. Early-year courses also make wide use of the TopHat (clicker) environment.

Section 5: High Impact Practices

Figure 1: Implementation of High Impact Practices (HIP) in courses in the Physics and Astronomy Program. Respondents were asked "To enhance the student experience throughout the years in program, are you implementing high-impact practices in this course?" Data extracted from the PHAS course mapping survey. The data collected from all 12 PHAS courses.

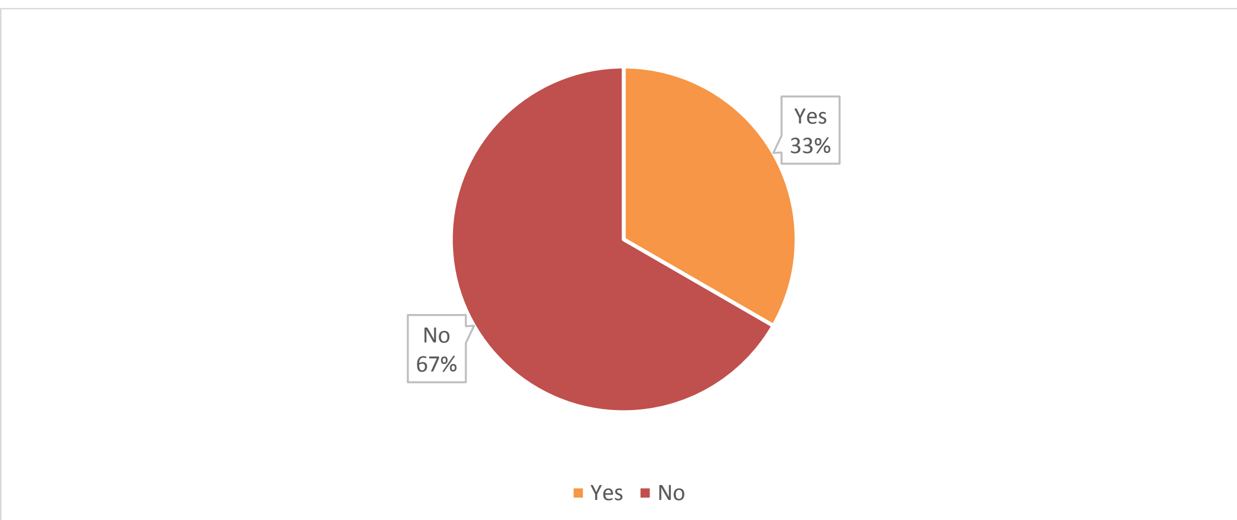


Figure 2: Types of High Impact Practices (HIP) implemented by instructors in Physics and Astronomy courses. Respondents were asked “If you answered yes, which of the following HIPs have you implemented in this course?” Data extracted from the PHAS course mapping survey.

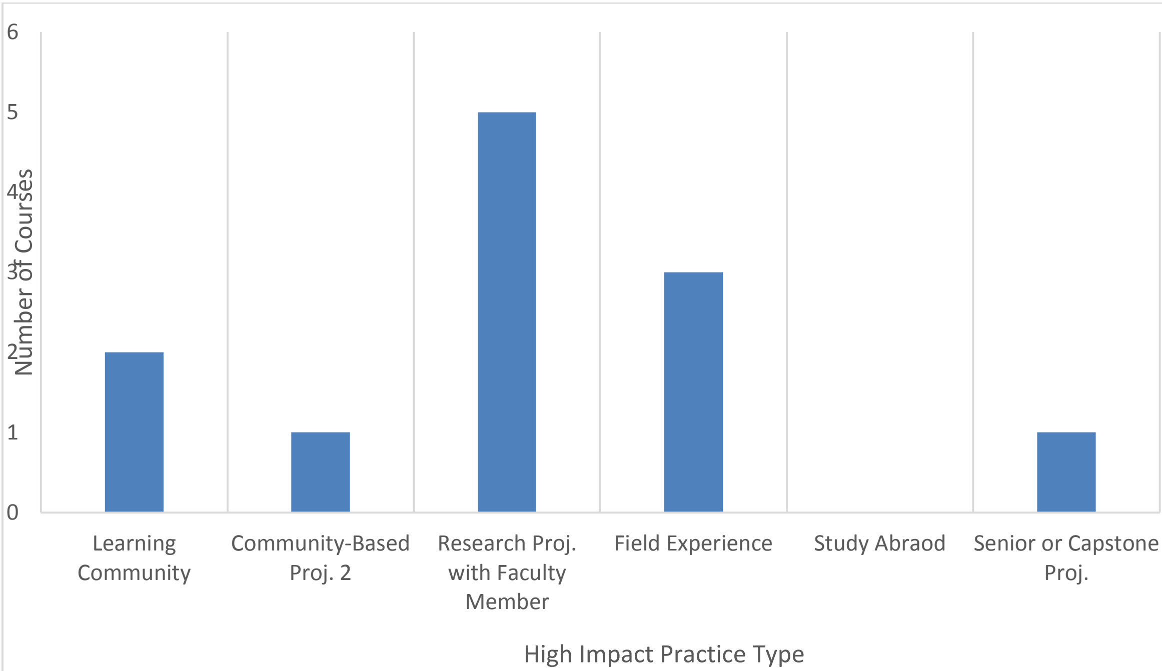
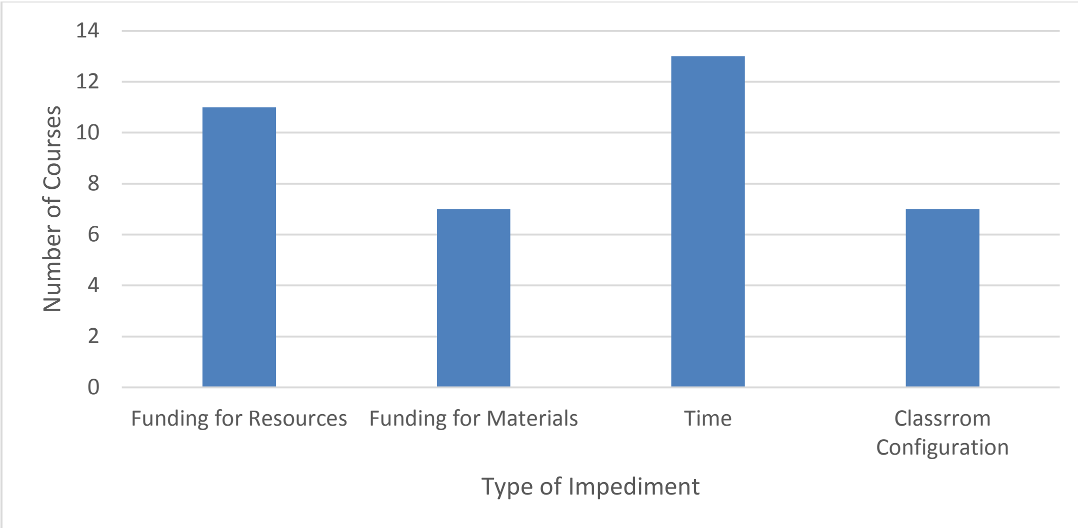


Figure 3: Impediments to implementing

ctices (HIP) in the Physics and Astronomy courses, as viewed by the Instructors. Respondents were asked “If you answered no, what are some of the impediments to implementing HIPs in this course?” Data extracted from the PHAS course mapping survey.



Other impediments:

ASPH	213	This is an introductory course that is required to expose students with basic knowledge of key concepts required for following courses. The number of students (80 at the start of the term) makes HIPs listed impractical.
PHYS	227	It's not appropriate for this class. It's an introductory class in the first year.

Figures 1 through 3 show the use of high impact practices (HIP) in PHAS courses. One-third of twelve PHAS courses whose instructors responded to the question "To enhance the student experience throughout the years in program, are you implementing high-impact practices in this course?" replied in the affirmative. Of these, the top three HIP identified were (in descending order of priority): conducting a research project with a faculty member, field experience, and "learning community." It should be noted, however, that the use of HIP in a given PHAS course depends strongly on the given instructor, and these responses likely do not capture the full range of HIP implemented in PHAS. For example, every year that PHYS 449 (Statistical Mechanics I) was taught, all students made a field trip to the UofC's Cogeneration Plant, but this practice has not been continued in more recent years.

The notable exceptions to this instructor variability are the senior and honours thesis courses PHYS 599 and 598, respectively. In these mandatory single-term and two-term courses, respectively, students work on scientific research under the supervision of a UofC faculty member (not necessarily in the Department of Physics and Astronomy), and present their results both in oral and written format. In exceptional circumstances, these projects culminate in co-authored manuscripts published in scientific journals. That said, no departmental resources are devoted to the operation of these courses; the unstated assumption is that supervisor research funds cover the costs of student work. In some cases, supervisors use funds from projects that are not meant to support undergraduate training of this type. In addition, while the courses are mandatory for students, not all faculty members are inclined to supervise students, leading to wide disparity in faculty workloads. If enrolment in PHAS programs continues apace, this crucial HIP is unlikely to be sustainable without additional resources.

Those who replied in the negative to the question "To enhance the student experience throughout the years in program, are you implementing high-impact practices in this course?" were subsequently asked "what are some of the impediments to implementing HIPs in this course?" The top reply was "time", followed by "funding;" "classroom configuration" and "funding for materials" rounded out the remaining replies. Many respondents commented that HIP were "not appropriate" or were considered "too ambitious" for the course.

That said, almost half (48%) of respondents were interested in implementing HIP in their classes, and many had strong ideas about what they might do given appropriate resources; please refer to the comments below Figure 4 for details. These courses span second to fourth-year PHYS and ASPH offerings, which suggests that resource considerations and institutional support are actually the most important impediments to implementing HIP within PHAS.

In fact, space resources are already a significant problem in the delivery of core courses as enrolment in PHAS programs has grown in recent years. For example, the computational physics laboratory space (maximum capacity 44 students) is too small to accommodate the current numbers of PHYS 481 students, and inconvenient overflow space has been required for the past several years. The PHAS instructor pool has historically been too limited to offer this course in two sections, and the infrastructure of Science Theatres is too antiquated and limited to allow growth. Similar pressures exist for other course offerings.

Section 6: Other Aspects

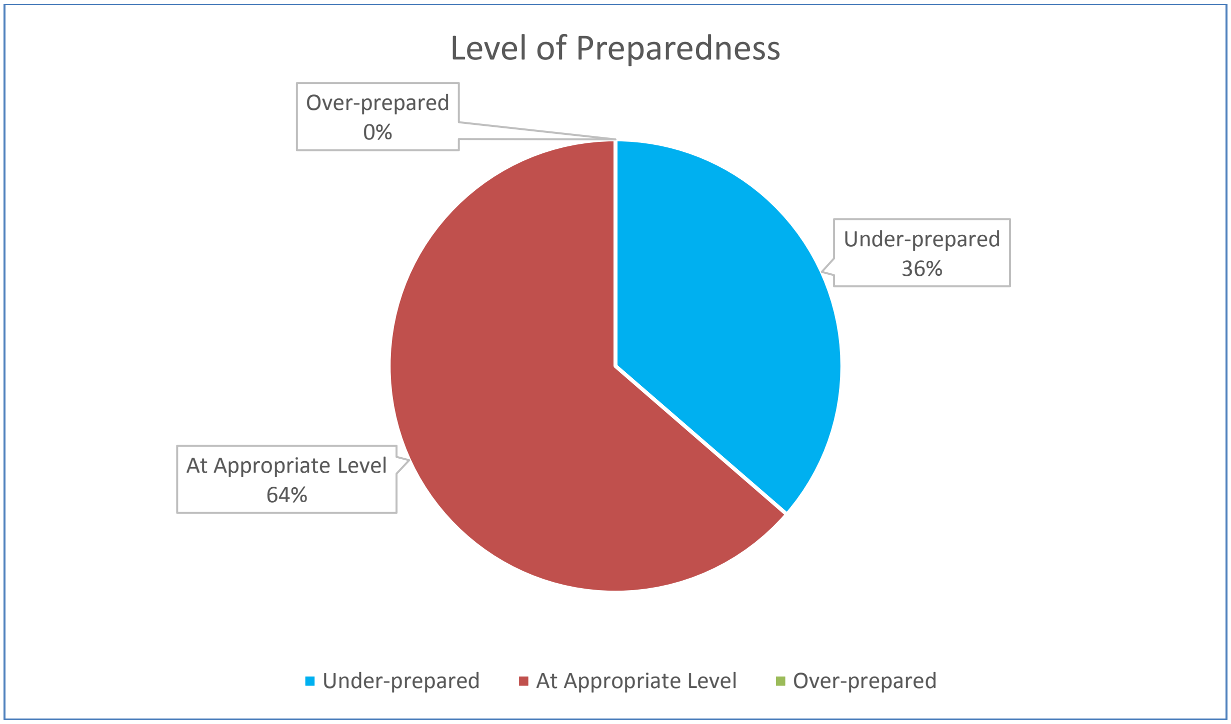


Figure 1: Level of Student Preparedness in Physics and Astronomy courses: "In general are students arriving to this class under-prepared, over-prepared, or at the appropriate level to begin to address the content of the course?" Data extracted from the PHAS course mapping survey.

Figure 1 shows the perceived level of student preparedness in their courses. Almost two-thirds (64%) of instructors felt that students are at the appropriate level coming into their course, and none believed that the students were over-prepared. The survey of alumni on this issue (Appendix III, Q14) yielded exactly the same ratio. In many cases, the preparedness concerns centered on mathematics rather than physics or astronomy/astrophysics. Though mathematics and applied mathematics courses are not formally a part of the PHAS curriculum mapping exercise, these courses form an integral part of our programs. Indeed, the verbal responses to the Undergraduate Student Survey (Appendix II) confirm this; examples of such comments include:

In addition, AMAT 433 (the Mathematical Methods in Physics service course for PHAS students offered by the Department of Mathematics and Statistics) is identified as a particularly problematic course. Comments from the Alumni Survey (Appendix III, Q12) confirm this; these are from students who graduated in 2016: "... Ditching the AMAT mathematical methods for physicists requirement in favour of higher level math options;" "The third year calculus course (AMAT 433?) drastically needs an update. Course material is sporadic, and often times worth an entire semester of study on its own. All the material is relevant at some point in the degree, but is not covered in any useful depth whatsoever I remember nothing from this course." These results strongly suggest that the mathematics series is not adequately scaffolded with the physics offering, and is a matter of concern for future study.

Another concern raised here is the fact that many required ASPH courses are offered every two years due to resource constraints within the Department. Because students take these courses in any order, the content is very difficult to properly scaffold. This leads to preparedness problems, and a situation where instructors often need to repeat essential information in every course. In addition, one cannot count on students having a common background in core PHYS topics, such as Statistical Mechanics and Quantum Mechanics. Again, this is a matter of concern for future study.

In addition to written work integral to most PHAS course, several courses have integrated oral presentations into the assessments. Details can be found in the comments below Figure 2. These of course include the Senior and Honours thesis courses PHYS 599 and 598, where students either given oral presentations or present posters. Oral presentations also make up part of PHYS 271, 325, 375, 501, 561, and 597, providing students with opportunities to express themselves orally at almost all course levels. Instructors of courses without an oral communication component are generally pessimistic about future implementation; impediments identified include large class sizes, lack of appropriateness, and time.

Analysis of Student and Alumni Survey Data (Appendices II and III)

Figure 1 through 26 in Appendix II show Student Survey response data for four years from 2013 through 2016; this is followed by written responses to questions, indexed by year. The survey itself, which remained unchanged over that interval, is given in text form at the beginning of this Appendix. For years 2013, 2014, and 2015, the survey was conducted just after the end of

Winter term 2013, 2014, and 2015. The 2016 data was collected within the first few weeks of Fall, 2016, so it was not able to capture the graduating-year cohort.

The data generally convey strong satisfaction with our course and program offerings, consistently over the four years we have conducted the survey. No attempt will be made to summarize all of the findings here. Rather, specific observations from the data will be mentioned here, with particular attention paid to specific issues arising, positive and negative.

Figures 2 and 3: “My instructors generally look out for students best interests” and "My instructors have taken a personal interest in my academic progress and achievements," respectively. The data for 2013-2016 for these questions are overwhelmingly in agreement or neutral. The 2014 NSSE data, Appendix V, paint a slightly different picture, however; students responded overwhelmingly with "sometimes" or "never" to all questions "During the current school year, how often have you talked about career plans with a faculty member?" "During the current school year, how often have you worked with a faculty member on activities other than coursework?" "During the current school year, how often have you discussed course topics, ideas, or concepts with a faculty member outside of class?" and "During the current school year, how often have you discussed your academic performance with a faculty member?" These results point to a relatively high level of dissatisfaction with opportunities for students to interact with instructors in 2014, notwithstanding the positive data in the PHAS student survey.

Opinions on the engagement of instructors with students on career opportunities and students’ perceived development of skills for future careers come up as mixed in both the undergraduate student survey and the NSSE data. In the undergraduate student survey, to the question “What do you like about how the Department of Physics and Astronomy interacts with undergraduates?" a student in 2013 replied “a lot of the profs talk to us about real world applications and things we should know about if we want to pursue careers as physicists/things they do for there jobs that i wouldnt know about from reading stuff online;” and in 2016: “The colloquiums are a very good addition as they give undergraduates an idea of where their careers can take them.” Yet to the question "What would you like to see improved in the way the Department of Physics and Astronomy interacts with undergraduates? How do you think this could be done?" a student in 2016 replied “I think one thing that is lacking for undergraduate physics students is communication about career opportunities outside of academia. It would be nice for the department to be more vocal about options for physics students who do not want to go into research after graduation.” To the question on the alumni survey (Appendix III) “Given your experiences since graduation, what kinds of experiences, courses, or supports do you think would strengthen the program?” one answer was “Encourage students to attend colloquia. More speakers (from alumni?) on alternative academic careers from a physics degree.”

Figure 7: "Some instructors used a variety of teaching methods in class to further engage students with content." While data for 2013-2015 show a large spread of opinions, the data has

strongly sharpened up in 2016, with the overwhelming majority of students in the "strongly agree" or "agree" category. This speaks to the recent introduction of innovative teaching methods in the classroom.

Figure 8: "Courses have promoted a deep understanding of the relevant content." The overwhelming majority of students have consistently responded with "agree" and "strongly agree." That said, the 2014 NSSE data given in Appendix V on student learning strategies present a slightly more nuanced picture. To the questions "During the current school year, how often have you identified key information from reading assignments?" and "During the current school year, how often have you reviewed your notes after class?" the responses are clearly centered on "sometimes;" the responses are even more skewed toward "never" for the question "During the current school year, how often have you summarized what you learned in class or from course materials?" Likewise, the responses to the question "During the current school year, how much has your coursework emphasized evaluating a point of view, decision, or information source?" were strongly biased toward "very little." These data suggest that instructors could offer a wider variety of teaching and assessment methods to promote a diversity of learning modes.

Figures 9 and 10: "I am satisfied with the selection of required Physics/Astrophysics courses available to me" and "I am satisfied with the selection of optional courses available to me," respectively. Both of these statements have historically yielded a broad range of responses, and this issue is a consistent cause for complaints, as can be seen both in the data here and in the open comments from current students in the section on open-ended comments and program alumni (Appendix III). PHAS has been aware of this problem for some time. Several causes have been identified.

One cause is capacity. Up until now, we haven't had a sufficiently large cohort of students in our senior year to be able to consistently offer a range of options. Because an undergraduate course cannot run with fewer than 10 students, we must limit our selection from year to year in order to ensure that a sufficient number of students are registered in a given course. At the same time, or current faculty numbers limit the number of courses that can be taught in a given academic year, and we are at capacity on this front as well. Recent years have provided relief on both of these fronts. We have hired a new Instructor in the past year, with another set to arrive in the new year. Our current undergraduate student numbers are strong, as shown in Table 2 of Appendix IV. From 2010 to 2014, the total number of students in PHAS programs grew from 179 to 268, an increase of almost 50%. If we are able to sustain these numbers, then we should have the student capacity to increase our senior-year option offerings. Indeed Tables 12 and 14 in Appendix IV show that our senior-year cohort has had a significant boost in recent years.

Another cause of some unhappiness with mandatory Astrophysics offerings is the fact that many core ASPH courses are taught only every two years. This is again a capacity problem;

there are currently too few astrophysics students to allow for each mandatory course to be taught every year. This causes many problems for students wishing to graduate in a timely fashion. According to Table 2 of Appendix IV, the maximum total number of students in Astrophysics programs was 84, which gives an average of 21 students in a given year, numbers consistent with the data in Tables 7 and 8 of this Appendix. While these translate into sufficiently large numbers to satisfy the "10 minimum students" rule, the program must also be robust against year-to-year fluctuations. The Department is currently working on a strategy to boost the number of students in Astrophysics programs.

Alumni comments related to this issue are found in Appendix III, Q12 and Q16. Among Q12 suggestions were an additional lab course for the Astrophysics program; more real-world / practical applications courses; larger course variety (for example, no nuclear or high-energy physics is taught - see also response 2 in Q15); and fewer required non-science courses (this has changed in recent years). Among the Q16 suggestions were "More labs or computational physics classes for the astrophysics stream," "... research, maker-style labs, model programming. An (extra-curricular) challenge to use these skills on arbitrary real circumstances would be most helpful;" "Broader choice in physics topics;" "More application-based courses (in nuclear or biotechnology or engineering), something that is more based on jobs rather than academia;" "Fluid mechanics would be nice for all this pipeline stuff. Computational physics is certainly an asset for graduates looking for industry."

Figure 13: "Student assessment methods used were generally fair." A strong majority of students responded with "agree" or better. That said, the 2014 NSSE data in Appendix V provide some additional insights into this question. In particular, there is a notable disparity in responses between first-year and senior-year students, and also between astrophysics and physics students. To the question "During the current school year, to what extent have your instructors provided feedback on a draft or work in progress?" astrophysics first-year students almost all responded "sometimes" and "often" while senior-year students almost all responded with "sometimes" and "never;" yet the vast majority of physics students at both levels responded with "often" or "very often." Similar trends in the responses (though skewed away from the "never" toward the "often" category) are found for the questions "During the current school year, to what extent have your instructors used examples illustrations to explain difficult points?" and "During the current school year, to what extent have your instructors provided prompt and detailed feedback on tests or completed assignments?" The inference is that there is a disparity between the perceived quality and timeliness of assessments between early and later years, and between astrophysics and physics courses.

One possible origin for increased student dissatisfaction with the quality of instructor feedback with the year in program might be the strong increase in student numbers over the past several years. As class sizes have grown, pressures on instructors have concomitantly increased. There also may be issues with the organization of particular courses. For example, to the question "What would you like to see improved in the way the Department of Physics and Astronomy interacts with undergraduates? How do you think this could be done?” one student responded quite negatively about the timeliness of feedback in PHYS 599/598; of course, one student’s criticism does not imply the existence of any fundamental issues.

Figure 15: "I had enough opportunity to perform independent research or skilled work, making use of my physics training." From year to year, there is consistently a wide spread of responses from "strongly agree" to "strongly disagree." Partly, this reflects on the real absence of opportunities in our courses for students to perform independent research or to use their learned skills, until their senior year when they undertake an independent research project. Also, PHAS programs do not have co-operative or internship variants. That said, students may perform research over the summer, funded through the NSERC USRA program, the UofC's PURE awards, or the Markin USRP in Health and Wellness. In practice, these opportunities are restricted to more experienced (upper-year) students, who can more readily make research contributions. Thus, the data also likely reflects a disparity in responses according to year in program, with students in early years more frustrated with a lack of research opportunities than those in upper years.

Figures 17-26 address the overall question "How would you grade the Physics/Astrophysics program for contributing to your growth and development in each of the following," with the focus topics "critical thinking," "problem solving," "oral communication," "technical writing," "experimental design and hypothesis testing," "laboratory measurements," "computer programming skills," "mathematical skills," "interpersonal skills / teamwork," and "project planning and completion," respectively. The data show that students are happy with the "critical thinking," "problem solving," "making laboratory measurements," and "mathematical skills," all of which constitute the technical core of their programs. They are moderately happy with "experimental design and hypothesis testing," "computer skills," "interpersonal skills / teamwork," and "project planning and completion," but are clearly unhappy with their growth in the areas of "oral communication" and "technical writing," Figures 19 and 20. These last two categories in particular are cause for concern, as in fact students have numerous opportunities to express themselves verbally throughout PHAS programs, including laboratory write-ups, homework assignments, term papers, and senior and honours theses. Several courses also require students to present their results, either as an oral presentation or a poster. The Department needs to follow this up with detailed consultations to find solutions.

The student survey data make clear that students are also not as happy with their opportunities for growth in teamwork and experimental design. This is quite surprising, as PHAS students have numerous opportunities to perform collaborative work in groups and teams. Many courses devote lecture time to having students work formally and informally in small groups. All first-year and several second-year courses have a mandatory laboratory component, in which students perform experiments and analysis as a group. PHAS students have numerous spaces where they can work together on assigned problems, including the computational physics laboratory (CPL) which is accessible 24 hours a day via a coded lock, a dedicated classroom across the hall from the CPL with movable furniture and surrounded by whiteboards, the Physics and Astronomy Students Association space, and the physics senior lab space (during business hours). It is likely that students do not fully realize that these aspects of their student experience qualify as teamwork, and that the Department needs to do better to communicate this to students. That said, opportunities are limited for students to work on research and/or experimental design (as opposed to experimental) projects. In any case, the 2014 NSSE results (Appendix V) on collaborative learning paint a naunced picture of the issue. When students were asked "During the current school year, how often have you asked another student to help you understand course material?" the majority of students replied "often" or "very often." For the question "During the current school year, how often have you worked with other students on course projects or assignments?" the spread of results is larger, but nevertheless the overwhelming majority of students responded in the range "sometimes" to "very often." This indicates that students are thinking of different aspects of teamwork, depending on the nature of the question.

Analysis of the Student and Course Data (Appendix IV)

Diversity:
The demographics of our undergraduate student population has been tracked by the Consortium for Student Retention Data Exchange, of which the University of Calgary is a member. As shown in Appendix IV, Table 2 and Figure 1, the ratio of male to female students has been steady at 4:1 from 2010 to 2014, even as the total number of students has increased. This ratio is higher than the historic Canadian national average of approximately 2.7:1 (i.e. 37% women) in math and physical sciences [WISE 2010], but unfortunately the results combine fields and data are not available for physics or astronomy separately. That said, statistics compiled in the U.S. [Ketsman 2014], where the numbers are much larger, reveal that the percentage of women graduating with bachelor’s and doctoral degrees in physics was closer to 20% as of 2013, a historical high since the mid-1960’s. In any case, the Department has much work to do to bring this gender ratio closer to parity, and the Department Head has been asking departmental members for advice on strategies for increasing gender diversity. One notable issue facing the Department is the exceptionally low representation of women among the faculty (only two full-time faculty members out of 26).

The 2014 NSSE data (Appendix V) indicate that students' exposure to diversity is not limited to class demographics. To the questions "During the current school year, how often have you included diverse perspectives in course discussions or assignments?" almost all students responded with either "sometimes" or "never"; likewise, the responses were highly skewed toward these responses for the question "During the current school year, how often have you tried to better understand someone else's views by imagining how an issue looks from his or her perspective?" This speaks partly to the nature of PHAS topics, which tend to be presented as facts to be remembered rather than ideas to be debated. Nevertheless, the data suggests that PHAS program offerings could do more to expose students to diversity in ideas, and to encourage reflection when exposed to new ideas. This conclusion is further reinforced by the majority "sometimes" and "never" responses to the questions "During the current school year, how much has your coursework emphasized evaluating a point of view, decision, or information source?" and "During the current school year, how often have you examined the strengths and weaknesses of your own views on a topic or issue?"

That said, NSSE students responses to the questions "During the current school year, how often have you had discussions with people from a race or ethnicity other than your own?" "During the current school year, how often have you had discussions with people from an economic background other than your own?" "During the current school year, how often have you had discussions with people with political views other than your own?" and "During the current school year, how often have you had discussions with people with religious beliefs other than your own?" the results were largely "sometimes" to "very often." The results indicate that PHAS students are consistently exposed to, and interact with, students with a wide array of ethnicities, economic backgrounds, and religious and political beliefs. That said, exposure to diversity appears to drop slightly from early to late in the program, a trend that is slightly more pronounced for students in astrophysics programs relative to physics. This might be partly due to a natural increase in like-mindedness as a relatively small cohort of students move together through their programs. It is important, however, that the Department explore the more serious possibility that diversity is decreasing over the duration of the program due to the more pronounced attrition among a particular group of students.

Retention:
Table 13 and Figure 8 in Appendix IV shows the median class size by level from Fall 2011 through Fall 2015. We focus on the majors, as there are many non-physics students who take PHAS courses at the 200 and 300-levels. The median class size averaged over all years where data exists gives 62, 68, 31, and 17 for 200, 300, 400, and 500-level courses, respectively. This shows that historically the population of PHAS majors drops by approximately a factor of two from second to third year, and another factor of two from third to fourth year; the data therefore suggest a 75% attrition rate. That said, for the most recent cohort where we have data (Fall 2014 to Winter 2015 cohort), the numbers are 69, 76, 34, 28, which is closer to a 50% attrition rate over the program. Thus, the retention rate appears to be improving in recent years. Furthermore, according to Table 14, between 2011 and 2014 the average number of students graduating with B.Sc. degrees in physics and astrophysics was 24, which is an attrition factor of approximately 2.7 from first-year student populations. Given the inherently difficult nature of PHAS courses, this attrition rate may not be significantly different from the national average. Though Canadian data are unfortunately unavailable, STEM (Science, Technology, Engineering, and Mathematics) retention was found to be on the order of 40% in the U.S. [PCAST 2012], which is almost identical to our average retention rate (37%). Thus, PHAS retention rates are likely not particularly unusual.

Action Plan

Based on the findings described above, the Department of Physics and Astronomy recommends the following actions.

- Course content and delivery:
  - Look at PHYS 341/343 course content: Should all topics be considered as advanced in a second-year course?
  - The content of AMAT 433 needs to be re-evaluated to ensure that it meets the needs of PHAS program offerings.
  - Ethical Practice: Though it is the 7th pillar of the PHAS Program Outcomes, few courses touch on this and related issues, such as sustainability and social responsibility. PHAS will explore how to incorporate ethical practice and understanding into more course offerings.
  - Approximately one-third of courses implement some form of high-impact practices (HIP). Yet while almost half of instructors who currently did not employ HIP were interested in doing so. Top impediments to doing so were "time", "funding;" "classroom configuration," and "funding for materials." in order of importance. Many respondents commented that HIP were "not appropriate" or were considered "too ambitious" for the course. The PHAS department needs to devote resources to promoting the use of HIP in PHAS course offerings.
  - The data suggest that courses instructors could offer a wider variety of teaching and assessment methods to promote a greater diversity of learning modes, and therefore improve student success. The Department should commit resources and concrete strategies for the promotion of creative and effective teaching and learning practices.
  - Students have indicated that they would prefer more opportunities to express themselves, both in written and oral formats. While in fact students' written work is evaluated throughout their programs, oral presentations are few. Furthermore, other than in laboratory write-ups, students are not trained in effective writing, presenting a logical argument, etc., nor is their writing often evaluated in this context (usually instructors are more focused on the physics). As these skills are key in the workplace, the Department could consider strongly encouraging students to enroll in a course that teaches these skills, perhaps as one of the students' non-science option courses.

- Program structure and delivery:

- Explore options for offering ASPH courses yearly, in order to properly scaffold the course information, and to minimize frustration among both instructors and students.
- There appears to be general dissatisfaction with opportunities for students to interact with faculty outside of the classroom, and generally with the PHAS department's expression of interest in students' livelihoods. The Department should explore new avenues for student engagement and career advising within the PHAS programs.
- Students have consistently expressed frustration with the selection of senior-year PHAS options. The Department is aware of the problem, which historically has been due to a combination of teaching capacity and senior-year student numbers. Some of these pressures have recently been removed, however, and the Department should again devote some thought to solving this persistent issue.
- Students have expressed frustration with opportunities to perform original scientific research (individually or part of teams) throughout their PHAS program. While all senior undergraduates perform independent research as part of their senior or honours theses, performing research earlier is mostly restricted to summer research projects, accessible only to the students with the highest GPAs. The Department should explore the possibility of instituting team-based research projects, possibly those that span several years and simultaneously engage students with different background and at different stages of their programs.

- <u>Benchmarks:</u>
    - While ethnic diversity among students within PHAS courses appears to be strong, the female to male ratio has been fixed at approximately 1:4 for several years. The department must do more to attract women to PHAS programs and to encourage them to remain. A likely contributor to the relatively low female enrollment is the critically low ratio of female to male faculty members, which sends the discouraging signal to students that PHAS is a predominantly male domain. It also signals limits to female instructor mentorship. The Department must work exceptionally hard over the next few years to correct this long-standing problem.
    - PHAS programs suffer from an attrition factor of approximately 2.7 from first to senior year. While not alarming -- PHAS courses are notoriously difficult -- the Department should conduct various surveys to determine the causes of the attrition to determine if there are fundamental (and modifiable) issues.

References

- [Ketsman 2014] Olha Ketsman and Carolina Ilie, Student Retention in STEM: Exploration of the Gender Gap, DBER Speaker Series (http://digitalcommons.unl.edu/dberspeakers/49, 2014).

- [PCAST 2012] Producing One Million Additional College Graduates with Degrees in Science, Technology, Engineering, and Mathematics, President's Council of Advisors on Science and Technology, (Public Release Tuesday, February 7, 2012).

- [WISE 2010] Women in Science and Engineering, Produced by the Corporate Planning and Policy Directorate, Natural Sciences and Engineering Research Council of Canada, Ottawa (November 2010).