PENNSTATE

Analysis of the Undergraduate Curriculum

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1. Introduction

This analysis encompasses the undergraduate curriculum at The Pennsylvania State University (Penn State), University Park campus. The introductory physics curriculum has several different levels which cater not only to the intended physics major but also to the general education requirements of the student body, in general, and those students in technical fields, such as engineering, who require a background in physics. These tracks will be discussed in detail. At the advanced undergraduate level, where the student demographic is effectively reduced to the major students in the field, has several different tracks of its own, including options in acoustics, electronics, teaching, medical physics and general physics. The default track that major students pursue is the general physics option which prepares the student for graduate study or other career paths after graduation. Since the foundation for these options are generally the same as far as advanced core courses are concerned, the advanced curriculum will be discussed in the general sense and if a statement creates the question as to if a specific option is being addressed, it can be assumed to be the general physics option.

The major observation of this analysis is the disparity in the curriculum from the introductory sequence to the advanced major courses and the findings are summarized in the table contained in Appendix 1.

2. Theoretical Philosophies of the Curriculum

The physics curriculum demonstrates, primarily, a structure of the disciplines philosophy reinforced, secondarily, by the traditional philosophy.

The aim of the curriculum is to develop each student's intellect to think critically, test theories and push the frontiers of physics (a goal to be accomplished after being indoctrinated through the curriculum). This is illustrated through the use of the combined media (at least at the introductory level) of lecture, recitation and laboratory exercises. Due to the different approaches taken by the introductory and advanced major courses, these will be discussed separately.

The introductory physics curriculum has three branches: 1) concept based physics ("physics for poets") {PHYS 001}, 2) algebra/trigonometry based physics ("college physics") {PHYS 215 and PHYS 265}, and 3) calculus based physics ("university physics") {PHYS 211-214}. The student demographic is, respectively, students in non-technical fields who need to fulfill a general education requirement, technical/science majors (mostly life sciences) who need a slightly more rigorous and complete physics base, and physical science/engineering majors who require a high level of mathematics prerequisites and a high level of physics comprehension to complete their major (mathematics majors also enroll for their applied mathematics prerequisites).

Philosophy wise, PHYS 001 is conducted almost entirely in the traditional philosophy as evidenced by the almost sole curriculum media of lecture accompanied by small demonstrative lab projects. PHYS 215 and PHYS 265 begin to draw the student into the structure of the disciplines fold. Topics are presented in lecture to large class sizes of approximately 200 students for two periods a week and then students meet in smaller class sizes of about 30 students led by graduate teaching assistants where lecture is reviewed, problem solving skills are honed and small quizzes are administered. For another class period, the students again meet in small class sizes of about 30 students to complete laboratory exercises where lecture concepts are directly tested and verified. Lab sections are often led by advanced undergraduate physics majors under the supervision of the staff lab coordinator. All of the subjective grading (quizzes, homework and labs) is done by the graduate and undergraduate assistants. The midterms and final are objective multiple choice in form and are mechanically graded by the University Testing Services (UTS). This methodology is primarily structure of the disciplines in that students are brought up in the problem solving skills a physicist uses every day and is taught through laboratory sessions to question theories and to discover for themselves the way the world works through the scientific method—which is useful to all students regardless of major.

PHYS 211-214 before the reform, expounded upon in section 3, resembled the format of PHYS 215 and PHYS 265 with the exception that there were more semesters required for the completion of the sequence and, by this, each topic in physics is covered in greater depth with a higher level of mathematical sophistication. The media shifted towards blending recitation and laboratories together with computer aided instruction after the Introductory University Physics Project (IUPP) established by the American Institute of Physics (AIP) and funded by the National Science Foundation (NSF). Students are still introduced to concepts in large lecture sections of about 350 students and then break into smaller groups of about 25 students for recitation and lab similar to PHYS 215 and PHYS 265. In lab, students conduct experiments with electronic data collection equipment that interfaces with a computer in smaller "lab groups" of about 3-5 students. The lab and recitation sections are conducted by graduate teaching assistants who are closely supervised by staff lab coordinators. Again, this reflects a strong structure of the disciplines influence. It is also clear to see the underpinning of the structure of the disciplines philosophy with the traditional philosophy by the common utilization the lecture media for concept introduction.

The advanced major courses are shifted more toward the traditional philosophy in that laboratory experiences dwindle to a minimum (only one laboratory class and one elective course that includes a laboratory is required for completion of the curriculum) as well as student collaboration (this is predominant however in the extra-curriculum). It remains primarily structure of the disciplines in that problem solving abilities are cultivated, not sheer regurgitation of material, but more traditional than the introductory courses due to the virtually sole dependence on the lecture media.

3. Motivation for Curriculum Development

Almost every aspect of everyday life is influenced by the rapid evolution of technology and the availability of computers—including the communication of information to students. Several programs have set out to evaluate the new pedagogies that are developing out of the information age. Most prominent is the IUPP. The major pretenses of the project are:

1. Contemporary physics should be a prominent part of the course content.
2. The total course content should be reduced relative to the status quo. Fewer topics should be covered in more depth (the "less-is-more" philosophy)
3. The course content should have coherence. The topics making up the subject matter of the course should be linked by a story line. The phrase "story line" describes a single or small number of organizing themes which can be used to link sequential segments of the course into a pattern with structure evident to the student.

Although very difficult to attack effectively via a physics content-centered project, keep a fourth guideline in mind:

4. The needs of all student constituencies in the introductory course should be met. (By "constituencies" is meant several varieties of identifiable student groups—different academic interest groups such as pre-engineering or pre-medical students, students with differing levels of background in physics or mathematics, students from underrepresented ethnic groups, or women.) [1]

Although the physics curriculum at Penn State was not intentionally modeled after the IUPP it follows its pretenses' footsteps. In the words of Dr. Richard Robinett, director of undergraduate studies for the Department of Physics, the motivations for the physics curriculum reform included a "wish to have a core up-to-date pedagogy, delivery, computer-based learning possibilities, emphasis on conceptual issues, use of modern computer tools at an early stage, addition of lab to the old PHYS 201 which didn't have a lab, and a wish to more tightly couple lab/lecture/recitation activities so they reinforced each other."

Previously, the calculus based introductory physics curriculum was composed of a three-semester sequence labeled PHYS 201 (Classical Mechanics, assigned 4 credits), PHYS 202 (Electricity and Magnetism, 4 credits), PHYS 203/304 (Thermodynamics, Optics and Modern Physics, credit varies). PHYS 201's media included lecture and recitation without lab. PHYS 202 included lecture, recitation and lab. PHYS 203 and 204 were exactly identical in content with PHYS 203 including only lecture and recitation while PHYS 204 included lecture, recitation and lab. For that reason PHYS 203 and 204 were assigned different credit values—3 credits for PHYS 203 and 4 credits for PHYS 204. The disparity between PHYS 203 and 204 was the result of the high demand for physics courses to support all of the engineering curricula that are quite prominent with Penn State being a land-grant university. Having variation with the depth that the more modern, peripheral physical subjects are covered that either are rarely considered in engineering or are covered in other engineering focused courses allows for more applicable education of engineers. After the curriculum reform, to be described in the next section, PHYS 213 and PHYS 214 were formed as separate independent two credit courses that deal with the different elements of the older PHYS 203/204 independently.

The planning process began with discussions in the Continuous Quality Improvement (CQI) team about the applicability of the introductory physics curriculum for the engineering students. This was brought to the attention the Intro. Course Committee who then began a dialogue with the College of Engineering who did extensive, department-by-department research about what physics concepts they most desired and in what combination. With this in mind, the department also sought out the opinions of other on campus and off campus sources. On campus sources included the deans of both the College of Engineering and the Eberly College of Science (ECoS) and the provost for undergraduate education. Off campus sources included the faculty at the satellite campuses in the Penn State system especially in those departments that would be directly affected by the curriculum change, and administration and faculty at other institutions not affiliated with Penn State, both at the two-year level and the four-year level. Representatives from the discipline in general who have stakes in the education of future physicists where also consulted [2]. The communication between all of the sources was characterized by Dr. Robinett as very "back-and-forth" on the issues. Once the curriculum aspects were settled upon, extensive documentation was compiled and submitted in petition for the revision of the physics curriculum to the faculty senate (q.v. Appendix 2).

The Intro. Course Committee was composed of faculty members from both the University Park campus and the satellite campuses in the Penn State system. Although students were not represented on the committee proper, they gave extensive feedback. According to Dr. Robinett, "Special lab sections of the older PHYS 201/202 were tested using the new format, new experiments, new labs and new recitation activities to see how they went over. Original labs often developed using smaller honors courses that were then generalized to larger courses." The subject matter was not only represented by the faculty on the committee but also by the discipline representatives consulted. Milieu was also represented through the consultation with the administrative units of the university such as deans' offices and the provost to insure that the curriculum was in line with the relative mission statements and politics.

As far as the other introductory courses are concerned, only minor adjustments are currently being made. "PHYS 001 is being revamped as part of a 'demonstration' program in which five or six colleges and departments are being asked to 'show off' some innovations in redoing the course by adding innovative video snippets, collaborative 'outside of class experiments,' web-based homework and a number of other activities," stated Dr. Robinett. The PHYS 215 and PHYS 265 sequence has remained unchanged for some time and is not in line for any revisions in the near future. Such is the case for the advanced courses as well.

4. Purposes and Content

The student demographics vary widely between the introductory and advanced physics curriculum. As developed in section 2, the introductory courses are composed of an interdisciplinary student demographic while the advanced courses are primarily disciplinary. To accommodate the needs of those students who require a more functional physics base, such as engineering students, the introductory courses intend to train students to produce utilitarian outcomes. The course content focuses towards the vocational needs of the interdisciplinary student giving them specific problem solving skills to take with them and use in their respective majors. Advanced courses are directed to the physics majors who, due to the varied paths pursued by the graduates, are in need of an education which covers the topics of physics in depth. The varied paths include graduate study, academic positions, and engineering positions. Since the curriculum cannot predict the future duties of its pupils, it has no choice but to provide an education.

The curriculum expresses its purposes in the form of mission statements (university, college and program level) as well as more specific goals communicated by syllabi. However, the messages conveyed in the mission statements are ambiguous in general with the exception that they all express the goal of excellence in research and education—a relatively obvious statement. The university mission statement yields the most specific information in the form of articulated core values and strategic goals [3], the ECoS mission statement are necessarily general [4] but are much more descriptive than the department statement:

> Our goal is to be renowned for the creation of knowledge in physics accomplished by faculty who excel in research and scholarship and provide superb education to our undergraduate and graduate students. [5]

This statement is virtually verbatim the vision statement of the ECoS. Since there is a lack of specific outcomes that the curriculum desires, the syllabi serve this purpose. In general, the concepts that are too be mastered in the course of the semester are clearly outlined as well as what will be expected of the student has far as exams, homework and, in those courses with lab components, lab exercises are concerned. In light of this curriculum being predominantly structure of the disciplines, it seems appropriate that the curriculum expresses its purposes at the course level which deals with the specifics of a course rather than the broad mission statement. The mission of the department is implicit in the structure of the knowledge and therefore relatively unspoken on that level.

The learning objectives for the introductory student follow directly from the training context of the curriculum. To fulfill the utilitarian ends, the program emphasizes content with a special emphasis on processes by teaching specific skills, procedures and methods. Advanced courses emphasize content almost exclusively by teaching facts, terminology and principles. This is not meant to imply that the advanced courses do not value the problem solving skills that are indoctrinated through the introductory courses—the meat of every physics course is problem solving. But, it is expected that the problem solving skills of the physics major at the advanced level are developed enough to be easily adapted and applied to new concepts as they are presented removing the need for further training. This implies a bit of elitism here—if a student is under prepared, it is his or her responsibility to bring their skills to the level they need to be.

5. Assumptions of the Curriculum's Purpose and Content

The curriculum proper is not interdisciplinary in that the physics major's course work is constructed almost entirely of courses offered from within the department. In a broader sense, it caters to an interdisciplinary student demographic. This is of course obvious in those courses that are not intended for physics majors (PHYS 001, PHYS 215 and PHYS 265) but in the PHYS 211-214 sequence there is a wide variety of students that require this foundation to pursue the more technical majors such as engineering. Therefore, the introductory curriculum, more so than the advanced curriculum, is molded by the interdisciplinary nature of its student demographic.

As expounded upon earlier, the reformation of the PHYS 201-204 sequence into the PHYS 211-214 sequence was greatly influenced by the demands of the engineering curricula on campus. This input shaped the content of the curriculum by supporting the IUPP pretenses of selecting the meaningful content and focusing on the student constituencies and reducing the course content to the relative status quo. This focuses the curriculum's purpose from broad topic coverage with little depth to a narrow, carefully selected group of topics which are explored with a greater amount of depth so that students may be more productive in the use of these topics.

The advanced curriculum's content and purpose is almost completely determined by its disciplinary nature. Nearly all students at this level are physics majors who now need to cover the 'nitty gritty' that was glossed over in the introductory sequence. No longer does the curriculum need to consider the needs of those students from outside of the department who require a solid, practical physics foundation—the curriculum is now free to cater to the structure of the discipline. The content of the curriculum is broken up into individual sub-fields which are covered in great depth with the purpose of producing thoroughly versed physicists capable of utilizing all the subtleties of the field to whatever activities they pursue after their matriculation.

Being involved with the physics curriculum as a graduate student and associating with the undergraduates through my role as a teaching assistant and working alongside them as a research assistant, I have observed the transition from the intellectual Darwinism of the introductory courses (often deemed "weed out" courses) into a form of obedience to the acceptance of laws placed in front of them for fear that questioning would lead to the silent scarlet letter of intellectual shallowness being placed upon them by popular opinion. After all, the "skilled" physicist can effectively think all concepts through the most subtle level. This is not meant to be taken out of perspective—questions are asked all the time in physics classes—but to ask a "stupid" question is feared by most students. This constructs a hidden curriculum which is a direct result of the elitism of the discipline. This pretentiousness is attenuated by the strong theoretical emphasis of the curriculum. As explained in section 2, there are only three courses in the advanced curriculum that have any laboratory experiences contained in them. The curriculum is therefore educating theorist regardless of whether the students wish to pursue theoretical or experimental physics upon the completion of the curriculum. This also serves to construct a hidden curriculum. After inquiring as to the reason for the strong theoretical emphasis in the curriculum, Dr. Renee Diehl, professor of physics, responded that the cause is not intentional but a result of lack of student lab space and was not an issue with equipment funding [6].

The intellectual Darwinism and obedience bred by the curriculum also serves to play a hegemonic role. As a result, there is a downplay of the creative abilities of students in favor of traditional skills. Not until students advance to graduate study are they truly encouraged to challenge every aspect of physics and take these new conceptions to push the frontiers of the discipline. By this, the purpose of the advanced undergraduate curriculum is to *tell* the students what physics *is* and not until the graduate curriculum are students challenged to ask, *"What can physics be?"* This also illustrates the assumption that many students will advance to graduate level education which is verified by the AIP's *"Physics and Astronomy Senior Report: Class of 1998"* [7] which shows the roughly half of graduation seniors in physics plan to pursue graduate study.

The transformative roles of the curriculum are intrinsic due to the nature of the curriculum although the adoption of structure changing concepts is time consuming. Physics is constructed on the scientific method which constantly allows for corrections to its theories—one could call this a built in CQI program. So, if an experiment contradicts an established theory and is reproducible, it is eventually incorporated into the whole of physics, after extensive testing. Since the physics curriculum is primarily structure of the disciplines in philosophy, the curriculum content will change as new, revolutionary concepts are accepted. There is, again, a time lag between introduction of a concept to its acceptance and incorporation into the curriculum.

6. Organization of the Curriculum

As far as prestige among the disciplines, physics is second to mathematics for pure and fundamental thought. However, since mathematics is not a science, per se, physics ranks at the top of the natural sciences. In keeping with Penn State being a land-grant university, its engineering curricula dominate as far as prestige is concerned. Therefore, the physics curriculum's prestige depends on what point of view one wishes to take but, regardless of this, physics ranks among the top few curricula at Penn State.

The macro level organization changes as the student progresses through the curriculum. At the introductory level, most students have a high school background in physics although this preparation is not assumed. Therefore, a very vertical organization dominates. This is illustrated in the linear micro organization expounded upon later. One subject precedes another, building on each other but the structure of knowledge is no developed enough to allow fleeting digressions into other related sub-fields. This level of development occurs at the advanced undergraduate level where the macro organization remains relatively vertical but allowing for horizontal aspects to surface in the curriculum.

At the micro organizational level, the non-major student encounters a very linear organization. This may take place in any of the three introductory physics tracks expounded on in section 2. The topics covered are usually introduced in the following order although the depth to which each is covered varies with the track enrolled in (as is reflected in the number of semester required to complete each track's sequence):

***I** Vector/mathematics prerequisites*

***II** Classical Mechanics*

- **A** Newton's Laws
- **B** Work and energy
- **C** Momentum and impulse
- **D** Rotational dynamics

***III** Electricity and Magnetism*

- **A** Coulomb's Law
- **B** Electric fields and Gauss' Law
- **C** Electric potential and potential energy
- **D** Magnetism
- **E** Maxwell's Equations
- **F** Basic Circuitry
  - **1** Resistors, capacitors and inductors
  - **2** Kirchhoff´s Laws

***IV** Optics*

- **A** Lenses
  - **1** Converging
  - **2** Diverging
- **B** Mirrors
  - **1** Concave
  - **2** Convex

***V** Thermodynamics*

- **A** Three Laws
- **B** Mechanical equivalent of heat/ heat capacity
- **C** Entropy
- **D** Engines
- **E** Kinetic theory/statistical mechanics

***VI** Modern Physics/Quantum Mechanics*

- **A** Blackbody radiation/ de Broglie Waves
- **B** Hydrogen atom
- **C** Zeeman Effect/Compton scattering
- **D** Schrödinger wave equation
- **E** Heisenberg Uncertainty Principle

The above list is not all-inclusive but gives a general idea of content and chronology. The order, although generally accepted, is not absolute (e.g. thermodynamics comes in between classical mechanics and electricity and magnetism in the PHYS 215 and PHYS 265 sequence) (q.v. Appendix 3).

For the physics major, the linear structure outlined previously applies but it is repeated with ever growing sophistication forming a spiral structure (each loop representing a complete cycle through the outlined chronology).

Ideally, the incoming physics major has had between 1 and 2 years of high school physics instruction which covers the chronology roughly with algebra or, less likely, calculus. The material is again repeated (or in some cases introduced) with calculus in PHYS 211-214 and in greater depth than most high school physics curricula can offer. This usually comprises the first two years of the curriculum. In the final two years, the material is once again repeated through advanced courses using differential equations, special functions and other more advance mathematical techniques. Each Roman numerated heading in the chronology is investigated in a course unto itself and in great depth. Most physics majors plan to pursue graduate degrees and can expect to once again revisit the sequence with more sophisticated mathematics and models in their first year of graduate studies before going on to specialize in a particular sub-field (q.v. Appendix 4).

There is a disparity in the relationships between the various media employed at the introductory loop and the advanced undergraduate loop in the physics curriculum.

The introductory loop is very convergent in its teaching methods as it offers three main media and a few optional media that each focuses the student on assimilation and competence of the concepts of physics. The three main media include (as explained in greater detail in section 2) 1) lecture conducted by faculty, 2) recitation conducted by graduate teaching assistants, and 3) laboratories conducted by graduate teaching assistants or advanced undergraduates. The more optional and peripheral media include 1) the physics Learning Resource Center (LRC) which is an open tutoring session staffed with several graduate teaching assistants for two hours every school night (Sunday-Thursday), 2) external tutoring from the university, and 3) from other individuals including collaborative efforts with other students and the lecturer’s or graduate assistant’s office hours.

As for the advanced undergraduate courses, the prevailing but unspoken sentiment seems to be that those students moving on to more advanced work have proven themselves in the sense that they haven’t been "weeded" out by the rigor of the introductory sequence and do not need to be coddled any longer. The main media consists of lecture in the very traditional sense. Lab components are virtually nonexistent with the exception of PHYS 457W (Experimental Physics) which is a required course and PHYS 458 (Optics) and PHYS 402 (Electronics); of these two, one must be elected to meet graduation requirements. Because of the linear methodology of the structure of the knowledge, the sub-disciplines are easily related to each other since each student has run through the sequence twice and are quite knowledgeable in the sub-fields. So, due to the drastic reduction of media use overall, the few courses which include lab components and because of the relationships between of one sub-field to others at this level, I would deem the advanced undergraduate curriculum as being composed of mixed media (parallel and convergent).

Since the curriculum is organized around fundamental concepts and principles and from these the students are expected to derive for themselves problem solving skills and meaning, the curriculum is clearly organized in the top-down approach and is in agreement with all of the evidence discussed thus far. The structure of the disciplines is mirrored through the assumptions of the curriculum’s organization outlined in the following section.

7. Assumptions of the Curriculum’s Organization

In the sciences, knowledge is derived from a small set of general, abstract ideas. This is the physics curriculum’s fundamental epistemological assumption. The advanced undergraduate curriculum exemplifies this in that the knowledge of the disciple is given in its relatively raw form and given to students to string the theories and methods together to form a problem solving protocol. The student through this is then placed in the position of the physicist and sent out to fully discover physics’ knowledge structure. Clearly, this is entirely structure of the disciplines in philosophy.

The psychological assumptions of the physics curriculum also rest on the foundation of the structure of the disciplines philosophy. As stated as evidence for the epistemological assumption, the student is expected to fill the role of a physicist suggesting that the curriculum assumes that the learning processes of the student is similar to the inquiry processes of scholars in the discipline. The Learning Style Inventory (LSI) of David Kolb suggests that students with an assimilating learning style tend to gravitate towards careers in such fields as the physical sciences and mathematics [8]. This also supports the psychological assumptions the student will exert characteristics of abstract conceptualization over concrete experience and reflective observation over active experimentation—in general. However, due to the noted disparities in the introductory and advanced curricula, the introductory curricula swings more toward the active experimentation end of the spectrum catering to the converging learning styles as wells as the assimilating. This shift in psychological assumption is congruent with the fact that there is a more interdisciplinary student demographic in the introductory courses. Also, the department has made special efforts to make the curriculum more applicable to engineering students and, according to Kolb, engineering is a career path often pursued by students with this converging learning style [9].

As stated in section 6, most students have varying degrees of preparation for the introductory sequence through previous high school instruction. Again, this is not assumed. Prerequisite wise, PHYS 001 has no listed prerequisites, PHYS 215 and PHYS 265 only require mathematics prerequisites in elementary *College Algebra and Trigonometry* (MATH 022 and MATH 026 or MATH 040 or MATH 041), PHYS 211 requires the first course in *Calculus and Analytic Geometry* concurrently (MATH 140) while PHYS 212-214 requires MATH 140 with the its second semester continuation as a concurrent prerequisite (MATH 140 and 141). Of course, PHYS 215 is a prerequisite for PHYS 265, PHYS 212 is a prerequisite for PHYS 213 and PHYS 214 and so on. Please note that one of the major adjustments made to the calculus based physics introductory sequences is that PHYS 213 and PHYS 214 are two prongs of a fork emerging from PHYS 203/204 and therefore PHYS 213 is not a prerequisite for PHYS 214, and vice versa. This allows for the engineering departments to "pick-and-choose" what more peripheral topics they want their students exposed.

Prerequisites for advanced physics courses vary, all require the PHYS 211-214 sequence, and some require other advanced physics courses and different levels of mathematics. In general, the well-prepared physics major will have mastered *Matrices* (MATH 220), *Calculus and Vector Analysis* (MATH 230), *Ordinary and Partial Differential Equations* (MATH 251) and *Advanced Calculus for Physicists and Engineers I* and *II* (MATH 405 and 406, respectively) in preparation for the advanced physics courses.

8. Implementation of the Curriculum

Temporal

In general the curriculum does not require any special scheduling requirements other than making provisions to avoid the overlap of common courses many students take concurrently. The preparation time of professors is more than ample considering the average teaching load of a professor in the department of physics is less than one three to four credit course per semester. Considering that there are approximately 35 active professors in the department and approximately 25 undergraduate and graduate courses offered per semester that require separate instructors, it is clear to see that it is not uncommon for upwards of ten professors in the department to have no instructional duties in a given semester (visiting scholars and postdoctoral fellows often teach a course or two).

Physical

There are several special physical requirements that the physics department must provide for students that are common across the sciences and engineering—there must be laboratory facilities. As discussed previously, most of the introductory sequences rely heavily on such facilities while the advanced courses do not. The curriculum does not require special equipment that is not available within the department or on campus. This is due to the fact that virtually every institution of higher education has some form of physics curriculum which requires laboratory facilities creating enough demand to keep supply high and, as mentioned before, there isn't and issue with equipment funding. Perhaps, although not a piece of equipment, the lack of lab space could fit under this classification. As far as classrooms are concerned, most of the rooms commonly used for physics instruction reflect the curriculum's traditional influences. For lecture and recitation, the classrooms are arranged in rows of half-desks facing the instructor, some of the rooms going so far as to bolt the desks to the floor fixed in the arrangement—not just in the large lecture halls. Laboratory facilities are amply equipped with computers and the students work together in groups at larger tables (q.v. Appendix 5 for documentation of the department's facilities).

Organizational

There exist special organizational relationships, at least in the form of lines of communication, between the College of Engineering and the physics department as well as with the other departments located at satellite campuses in the Penn State system that promote the betterment of the curriculum as a whole. The congruence of the curriculum with program and institutional goals is difficult to access due to the relative ambiguity of the mission statements themselves. One can then deduce that the mission is implied by the structure of the disciplines philosophy which has for itself well defined goals. With the curriculum being dominated by this philosophy, the congruence is apparent.

Political and Legal

There are no official external agencies that the department must answer to as far as its own accreditation however, engineering has accreditation requirements by the Accreditation Board for Engineering and Technology (ABET) that focus on the physics and chemistry courses available to the engineering major—these matters where discussed in detail with the College of Engineering during the calculus based introductory course reformation and this lead directly to the splitting up of PHYS 203/204 into two separate courses PHYS 213 and PHYS 214. However, the department does offer itself to external evaluation as illustrated by the October 23, 2000 invited site visit of the Climate for Women in Physics committee sponsored by the American Physical Society (APS). The results of their evaluation will be discussed in section 10.

Due to the domination of the structure of the disciplines philosophy, the curriculum is consistent and appropriate for the instructor's attitudes, beliefs and competencies by definition. As an illustration, compare the texts used in the curriculum to the "Texts Most Frequently Cited as Undergraduate Preparation by the Chairs of Physics Graduate Departments," a list compiled by the AIP's Statistical Research Center [10]. The list is comprised of 14 advanced undergraduate texts in the fields of classical mechanics, electrodynamics, thermodynamics and quantum mechanics. In every field but one, quantum mechanics, the current text in use was listed again demonstrating how the acceptance in the discipline of something filters to its acceptance in the structure of the disciplines curriculum. The two texts commonly used at Penn

State for quantum mechanics (Robinett; Griffiths) were both published after this list was compiled.

9. Instructional Processes of the Curriculum

The physics curriculum focuses, course by course, on a specific sub-field of physics, as expounded on earlier (the introductory courses are able to cover several sub-fields in a single course due to their introductory nature but, nonetheless, each sub-field was focused on directly), whose written exams focus on problem solving ability. So much so that it is not unheard of for a student with a thorough, detailed solution but incorrect final answer to receive full credit and a student with only a correct answer and no solution to receive no credit. It isn't the answer that is important but the method one uses to arrive at it. After all, physics courses are not mathematics courses so, if one used the physics correctly but made an algebra or arithmetic mistake along the way, the grade is decided on the use of physics (although, more often than not, one will receive most but not all credit—algebra mistakes can kill in the real world). The physics curriculum also relies heavily on textbook resources (it serves as the student's "bible" as far as the mathematical description of the world is concerned) and exercises. All of these characteristics parallel a structure of the disciplines curriculum. The implementation of instruction is carried out exclusively in a teacher-centered fashion through lecture (and recitation for introductory courses) to the class as a whole with little individual attention or structured collaboration between students (although extracurricular collaboration is common and fostered through the undergraduate-graduate student lounge in 219 Osmond Lab). This characteristic is clearly traditional in philosophy.

These philosophies support the instructional processes and bridge the content and the purpose of the curriculum. Inherently, the content of any physics curriculum is the fundamental laws that govern the behavior of the world and universe. The purpose is to produce a physically literate graduate who will either go out into the world directly to translate the theories they have mastered into something productive for society—be it the creation of a material object or the teaching of physics to others—or to continue on with their education and push the frontiers of physics in the future. With this content and purpose in mind, the structure of the disciplines curriculum seems a logical choice in philosophy.

The physics curriculum has gained a reputation for being somewhat elitist in that the introductory courses have been deemed "weed out" courses. So, for those students who learn well by the instructional processes outlined, they will most likely succeed which is the fundamental goal of most non-major students—completion of the physics courses required for their major. For those students whose learning style does not fit the instructional processes outlined, they tend to struggle and, although both the department and university offer support services, these services tend to instruct by the same means as the course with the exception that the student is given more personal attention. This attention often leads to improved performance but the student continues to struggle with new concepts presented later on—the problem solving skills are not developed but programmed. Therefore, neither the curriculum nor support services have succeeded in developing the thought processes or problem-solving abilities of students whose learning processes do not match the instructional processes of the curriculum—hence its elitism.

10. Evaluation and the Curriculum

Student learning is primarily assessed with exams, homework and, where applicable, lab exercises. These have all been explained in detail previously. Student evaluations of the instructor and course work serve as useful evaluations of the curriculum as well as measuring student opinion on their own progress.

The curriculum itself is continually being evaluated by means of constant feedback from other departments on the University Park campus itself as well as the physics and engineering departments from other satellite locations in the Penn State system to the Intro. Course Committee. As mentioned previously, the department also opens itself up willingly to external evaluation as exemplified by the site visit made by the Climate for Women Committee. The results were positive in general and the recommendations were admittedly not gender related. There were two recommendations relating to the curriculum that resulted from interviews with female undergraduate students:

> Attention should be paid to quality of teaching, especially in the first year, when students are making up their minds about a major. Research shows that students are particularly vulnerable to leaving physics in their first year, and that women are more vulnerable than men because the small numbers make them more susceptible to suggestions that they do not belong...
>
> It would be helpful to have a mechanism for anonymous feedback to professors during a term. One student mentioned that the math department has such a system using the Web and that it is very useful. [11]

The anonymous feedback system is now functional and a screenshot is included in appendix 6. Although not directly related to curriculum concerns, the department has established its own climate committee with the intention of continually evaluating the atmosphere within the department with the aim of increasing the productivity of both the curriculum and the research conducted within it.

There are several statistics that would serve useful to evaluating the curriculum which include Graduate Record Exam (GRE) general exam and physics subject test scores of graduates who have taken the exam(s) and alumni surveys. There are several complications to gathering the results of the GRE scores. First, students who also major in other fields such as astronomy and astrophysics or mathematics with physics. So, unless those students list physics as their primary major, their test scores are often sent to the department of their primary major. Also, students are not required to release their scores to their undergraduate institutions at all. However, the use of alumni surveys would not only aid in the collection of these statistics but also on what the department's graduates pursue after the completion of the curriculum. With this information, weaknesses in the curriculum that may surface later in the graduates' life can be fed back to the department and corrective measures made.

An opportunity from the university-wide Teaching and Learning Consortium has given a wonderful opportunity to the department to make positive adjustments to the PHYS 001 curriculum; these adjustments have already been addressed in section 3. However, lack of funding is holding back the initiation of reformations to the PHYS 215 and PHYS 265 sequence.

11. Conclusions

The physics curriculum has many strengths to its credit including being situated within a research university and staffed with instructors who actively undertake the inquiry process of the discipline on a daily basis—an ideal environment for a structure of the discipline curriculum. This also introduces a weakness—given that the average course load of a professor is less than one course per semester, it is apparent that emphasis is given to academic research and not education within the department. This was also observed by the Climate for Women Committee as stated earlier.

One advantage of having faculty active in the discipline is the formation of centers for specialized study of a sub-field within the department notably the Center for Gravitational Physics and Geometry (CGPG) and the Center for Materials Physics (CMP). The CGPG offers one of the top ranked graduate curricula for the study of general relativity and gravitation but this resource is not filtered down to the undergraduate curriculum. It is therefore recommended that, at the very least, there be introduced at the advanced undergraduate level a required course in special relativity which would ideally be followed up by an elective advanced undergraduate course in general relativity. The CMP has filtered down to the undergraduate level sufficiently with courses offered in solid state physics, quantum mechanics, thermal physics and optics.

Only students involved with the university wide Schreyer Honors College are required to complete a senior capstone thesis in which students conduct independent research under the supervision of a faculty member often times working for them in their laboratories (this is a requirement of the Honors College and not the physics department). Considering that the advanced undergraduate curriculum is very teacher-centered, requiring all students to complete a similar capstone requirement would help move the curriculum to be more student-centered as well as preparing students to undertake independent inquiry which will be required of them regardless of whether they enter the workforce or continue their education after graduation. Also, this would allow a more inclusive evaluation of the graduating class' overall preparation gained through the curriculum. It is quite common for graduating seniors to have such research experience as reported by the AIP's *"Physics and Astronomy Senior Report: Class of 1998."* According the this report, 72% of graduating seniors reported participating in a physics research project and 28% sited that this research specifically took place as part of a thesis project. Even more astonishing is that 90% of graduating seniors who are proceeding on to graduate work in physics participated in some sort of undergraduate research [12]. Implementing a capstone thesis project for all graduating seniors would likely not run into much opposition considering that many physics majors voluntarily work in faculty labs for extra money or as part of a work study program while others participate in summer research programs such as the Research Experience for Undergraduates (REU) program supported by the NSF.

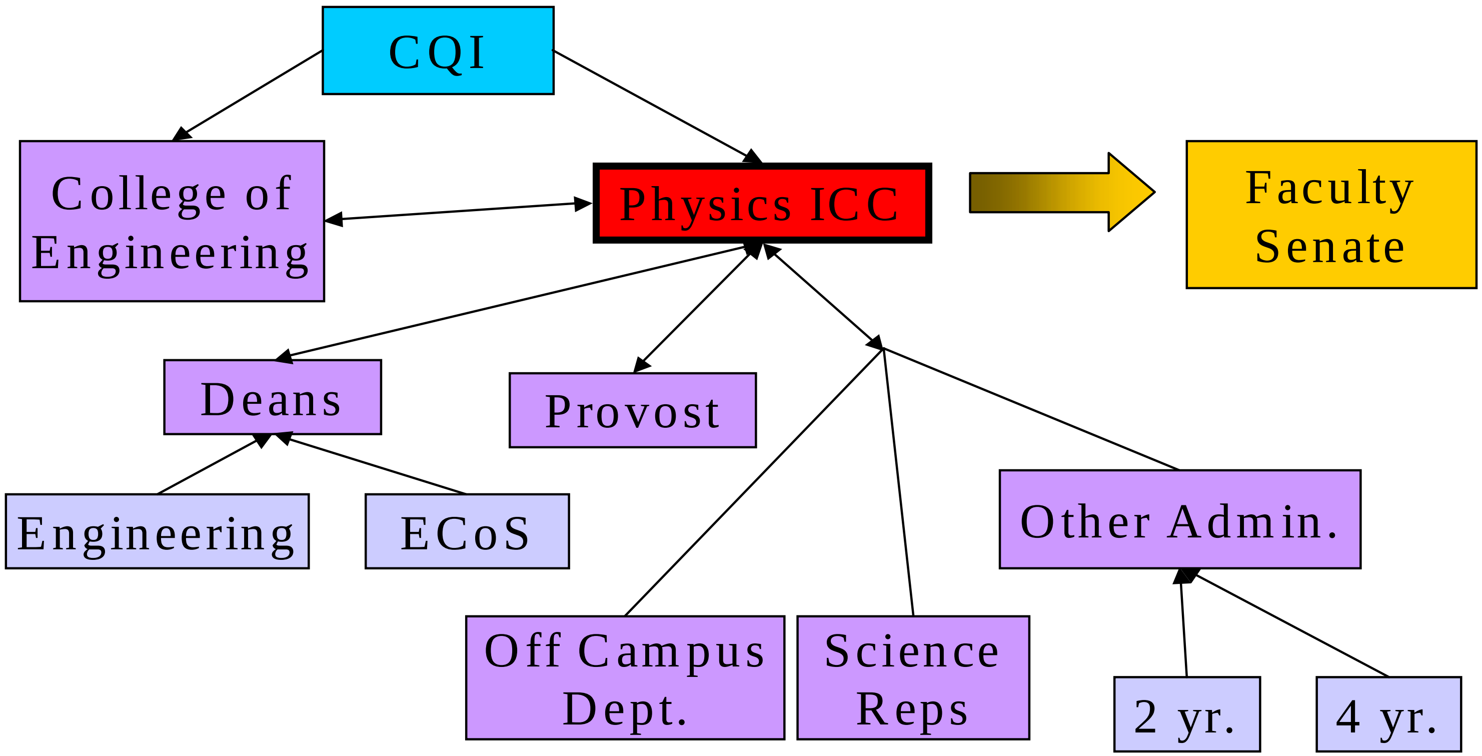
Appendix 1

Summary of the Analysis of the Curriculum

	Introductory Curriculum	Advanced Curriculum
Student Demographic	Interdisciplinary	Disciplinary
Theoretical Perspective	Structure of the disciplines with a touch of traditional	Structure of the disciplines with a greater emphasis on traditional
Educational and Training Contexts	Training	Education
Process vs. Content	Content with strong process influence	Content
Organizational Principles	Top-down	Top-down
Macro Organization	Vertical	Vertical with more allowances for horizontal digressions
Micro Organization	Linear	Spiral with each loop containing the linear concept chronology of the introductory curriculum
Media	Lecture/recitation/lab	Lecture

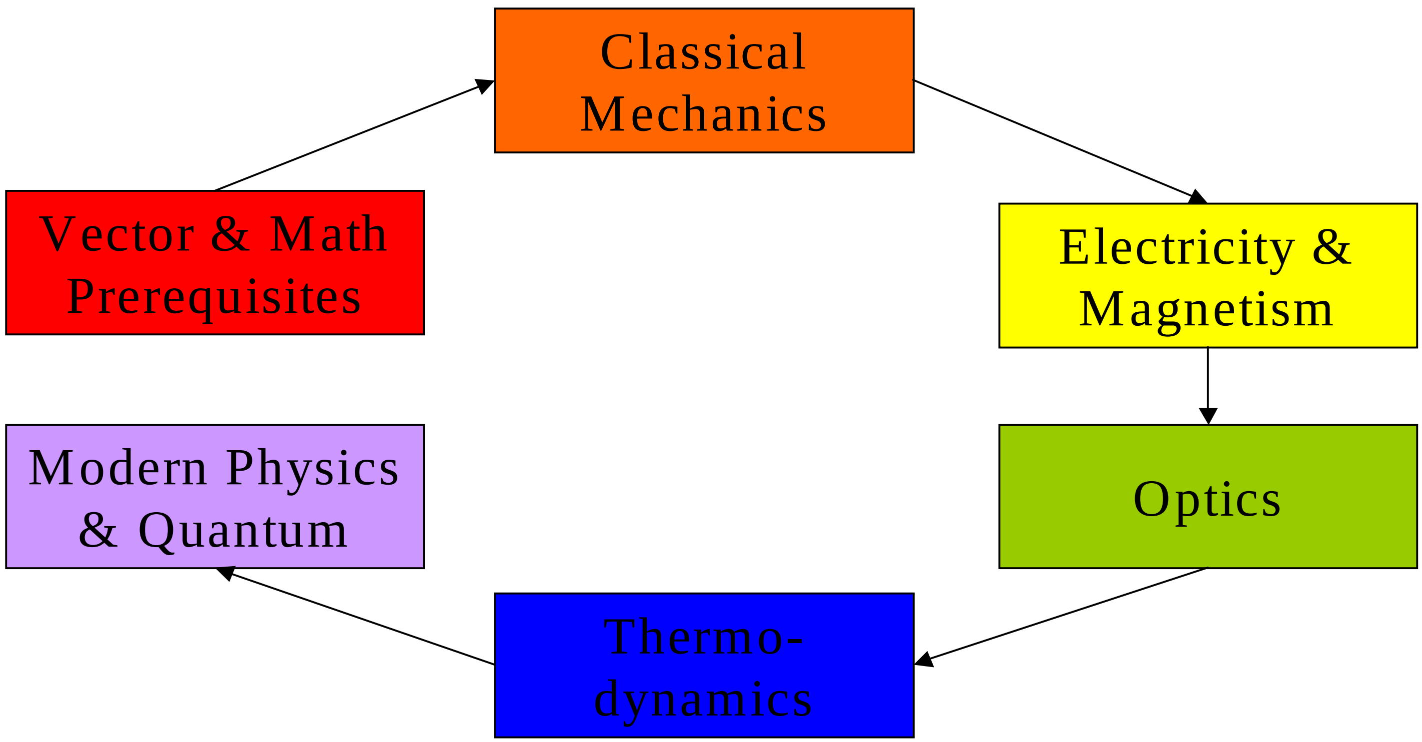
Appendix 2

Graphical Representation of Planning Process



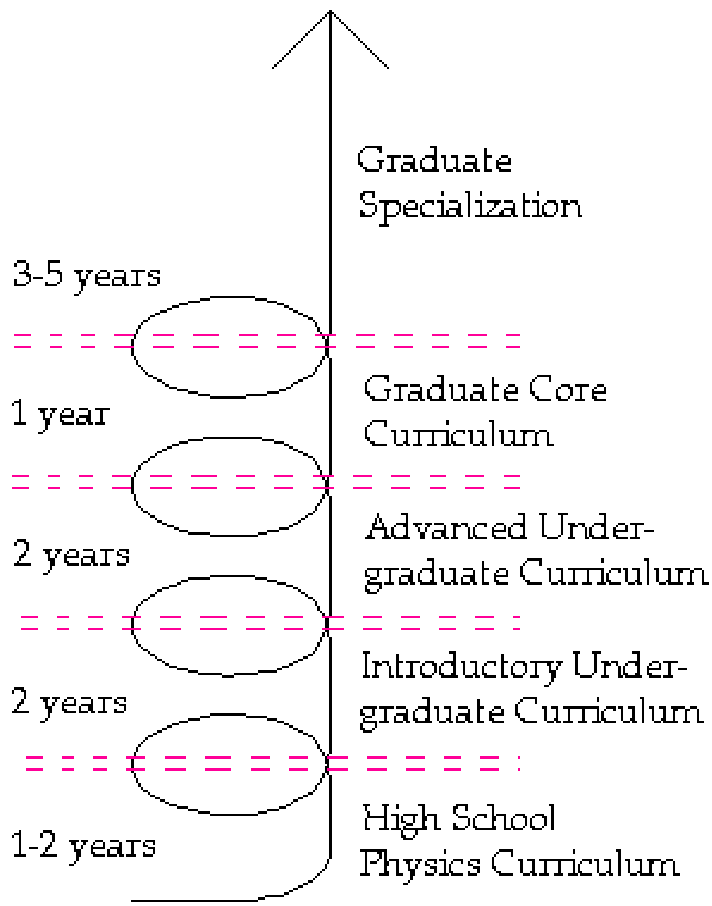
Appendix 3

Typical Concept Chronology: Linear Progression through the Spiral



Appendix 4

Spiral Macro Organization of the Physics Curriculum as a Whole



Appendix 5

Physics Department Facilities

Lab facilities for the PHYS 211-214 introductory sequence
(313 Osmond Lab)

A lab station outfitted with a computer and other equipment
(313 Osmond Lab)

Typical lecture classroom (N.B. fixed seating arrangement)
(110 Osmond Lab)

Student point of view in 110 Osmond

Right and left handed half desks bolted to the classroom floor
(110 Osmond Lab)

One of the two large lecture halls used for physics instruction
(119 Osmond)

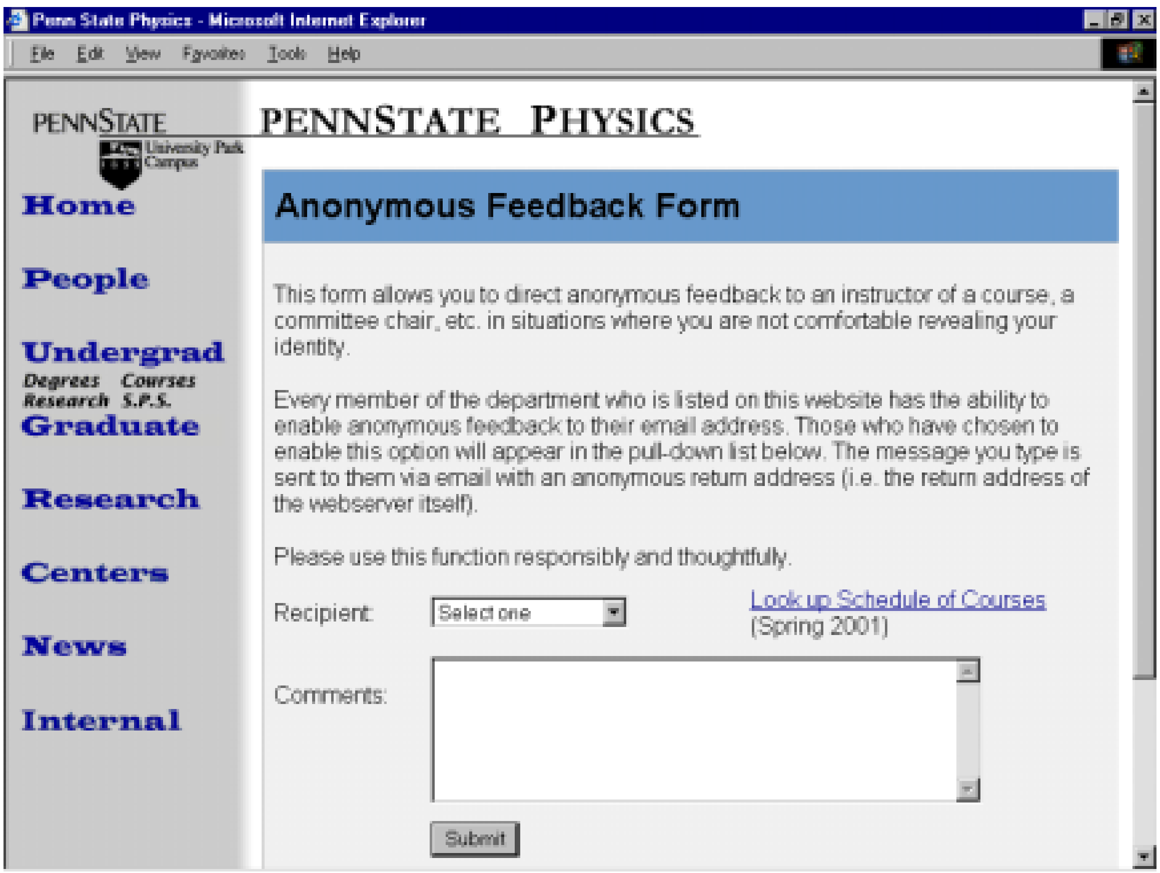
The physical science computer lab which is available to undergraduate students, graduate students and professors alike
(215 Osmond Lab)

Undergrad/graduate student lounge equipped with couches, desks, chalkboards, refrigerators and microwaves
(219 Osmond Lab)

Book collection available to students in the undergrad/graduate student lounge
(219 Osmond Lab)

Appendix 6

Screenshot of the Web Based Anonymous Feedback Program [13]



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