Proposed Physics Curriculum Changes and Applied Physics Program

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Motivation

It goes without saying that we have a strong interest in strenghtening our program and in serving our students by providing the best possible undergraduate physics education. In this document I have reimagined the Physics BS curriculum to try to address some of the areas I would personally like us to try to improve, including:

(i) There exists less-than-optimal coordination between physics and math coursework and, in particular, our students tend to exhibit weak *applied* mathematical skills even after taking the full set of mathematics courses.

(ii) I feel that the physics major is overly burdensome in terms of the number of courses and credits our students have to take, which makes it challenging for students to pursue other majors/minors (mathematics, astrophysics, data science, computational science), go abroad, start the physics major in their sophomore year, pursue the 3/2 engineering program, engage in independent research, and so forth.

(iii) And finally I feel that the current curriculum does not suitably prepare our students for graduate school and particularly for the GRE which takes place in the fall of their senior year.

Please note that this is a strawman proposal meant to engender discussion, not to create any hard feelings whatsoever! In particular, I have assumed that existing courses are not "owned" by anyone and have only approached this exercise from a high-level standpoint of what I think will best serve our students.

Current Physics BS

Before presenting my specific proposal I thought it would be helpful to review the current curriculum. Table 1 summarizes the current suite of courses a "typical" BS student would take. For comparison across the various proposed programs, the table also shows the number of student **Credit Hours (CH)** and **Faculty Contact Hours (FCH)**.[1]

[1] I have assumed three lecture sections and three lab sections of general physics (per semester) and one lecture and two lab sections (each) of Modern Physics and Electronics I.

Table 1:: Current Physics BS Curriculum

Fall Year 1	CH	FCH	**Spring Year 1**	CH	FCH
General Physics I	4	18	General Physics II	4	18
General Physics Review I	0	1	General Physics Review II	0	1
Calculus I	4	0	Calculus II	4	0
Software Tools for Physicists	3	3			
Total:	*11*	*22*	*Total:*	*8*	*19*
Fall Year 2	CH	FCH	**Spring Year 2**	CH	FCH
Modern Physics	4	9	Computational Physics	3	3
Electronics I	4	9	Thermal Physics	3	3
Calculus III	4	0	Differential Equations	3	0
Total:	*12*	*18*	*Total:*	*9*	*6*
Fall Year 3	CH	FCH	**Spring Year 3**	CH	FCH
Mechanics I	4	6	Electromagnetism I	4	6
Chemistry I	4	0	Experimental Techniques	2	5
Applied Math	3	0	Linear Algebra	3	0
Total:	*11*	*6*	*Total:*	*9*	*9*
Fall Year 4	CH	FCH	**Spring Year 4**	CH	FCH
Advanced Lab I	1	3	Advanced Lab II	1	3
Quantum Physics	3	3	Physics Elective	3	3
Total:	*4*	*6*	*Total:*	*4*	*6*

	CH	FCH
Grand Total:	**68**	**94**

Proposed Physics BS

Table 2 and the exposition below summarize the new proposed Physics BS curriculum. Courses in red are new while courses in blue are existing courses which would be modified as described below.

Table 2:: Proposed Physics BS Curriculum

Fall Year 1	CH	FCH	**Spring Year 1**	CH	FCH
General Physics I	4	18	General Physics II	4	18
Math for Physicists/Engineers I	1	1	Math for Physicists/Engineers II	1	1
Calculus I	4	0	Calculus II	4	0
Software Tools for Physicists	3	3			
Total:	*12*	*22*	*Total:*	*9*	*19*
Fall Year 2	CH	FCH	**Spring Year 2**	CH	FCH
Electromagnetism I	4	6	Mechanics I	4	6
Math for Physicists/Engineers III	1	1	Math for Physicists/Engineers IV	1	1
Calculus III	4	0	Differential Equations	3	0
Chemistry I	4	0			
Total:	*13*	*7*	*Total:*	*8*	*7*
Fall Year 3	CH	FCH	**Spring Year 3**	CH	FCH
Advanced Lab Techniques I	1	1	Advanced Lab Techniques II	1	1
Quantum Physics	3	3	Thermal Physics	3	3
Electronics I	4	9	Experimental Techniques	2	5
Total:	*8*	*13*	*Total:*	*6*	*9*
Fall Year 4	CH	FCH	**Spring Year 4**	CH	FCH
Physics Elective	3	3	Physics Elective	3	3
Honors Thesis			Honors Thesis		
Total:	*3*	*3*	*Total:*	*3*	*3*

	CH	FCH
Grand Total:	**62**	**83**

Description of Proposed Courses and Course Changes

- Math for Physicists & Engineers I, II, III, IV
  - *Summary*: A perennial problem in our physics courses, especially our calculus-based general physics sequence, is the fact that students do not learn the basic mathematical tools they need until well into their sophomore and junior year. Meanwhile, teaching math in our courses leaves less time for teaching physics! The goal of the *Math for Physicists & Engineers* four-course sequence—which would be taught in close coordination with the concomitant physics courses—is to provide students with the mathematical tools from calculus, linear algebra,

and differential equations they need to solve a wide range of elementary physics and engineering problems. These courses should also be structured to serve our applied physics majors (see below).

- *Example Topics*: vectors; matrices; coordinate systems (1D, 2D, 3D); differentiation; integration (1D); line integrals; circular motion; cross/scalar product; linear equations; matrix diagonalization; Taylor series expansions; div; grad; curl; Fourier analysis; special functions.
- *Issues to Consider*: We could consider enabling students to test out of one or more of these courses depending on their math background (or ability to learn the material on their own!). Also note that these courses would be taught by physics faculty.

- General Physics I
    - *Summary*: Not having to teach vectors, differentiation, and circular motion in general physics will allow for more time on all topics traditionally taught in this first semester of general physicsw, but especially rigid-body statics and dynamics, as well as gravity (which are typically rushed at the end of the semester or not taught at all). It's also possible that a chapter on basic fluids could also be taught here.
    - *Example Topics*: kinematics, forces, energy, work, momentum, rigid-body statics and dynamics, gravity, and fluids (possibly).
- General Physics II
    - *Summary*: Students frequently struggle with electromagnetism in this course because they don't have the requisite mathematical background yet. Moreover, the fact that we don't teach (general physics level) thermodynamics means that time has to be spent in *Thermal Physics* on these topics. Therefore, I propose we push electromagnetism (with the exception of the charge model and basic circuits) to students' sophomore year, freeing up considerable time for thermodynamics and fluids (if not taught in *General Physics I*). In addition, some basic topics from *Modern Physics* like the Bohr model of the atom and the Schrödinger equation could be introduced at the end of the semester.
    - *Example Topics*: fluids, thermodynamics, waves, optics, charge model, basic circuits, basic atomic/modern physics.
    - *Issues to Consider*: How will not teaching electromagnetism impact non-physics majors who only take General Physics I & II? Perhaps they can take General Physics IA & IIA instead (which would not change)?

- Electromagnetism I
    - *Summary*: I propose that this course becomes a sophomore-level course which introduces electromagnetism to our students for the first time, as well as special relativity. With the mathematical foundations of general physics completed and the concurrent *Math for Physicists & Engineers* courses, students should be able to tackle Maxwell's equations and electrodynamics at a reasonably rigorous level.
    - *Example Topics*: electrostatics; electric potential; current; magnetic field; induction; Maxwell's equations; light; special relativity; electrodynamics.
    - *Issues to Consider*: This course is currently a 400-level course in the catalog.
- Mechanics I
    - *Summary*: I propose that this course becomes a sophomore-level course centered around the Lagrangian mechanics formalism, supplemented with additional advanced topics not covered in general physics. Hamiltonian mechanics would *not* be introduced here.
    - *Example Topics*: particle dynamics; energy/work; conservative forces; rigid-body statics/dynamics; orbital mechanics and gravity; oscillators; rotating reference frames; Lagrangian mechanics.
    - *Issues to Consider*: This course perhaps more naturally belongs in the fall of the sophomore year but after a year of general physics students should really see electromagnetism then. Note that this course is currently a 300-level course in the catalog.
- Thermal Physics
    - *Summary*: I propose that this course become a junior level course which is taken *after* electomagnetism and mechanics. (In principle this could be taught fall of the junior year before quantum mechanics but I was trying to keep this as a spring course.) In particular, with the solid foundation of thermodynamics (from general physics, which of course would need to be reviewed), this course can become more advanced and focus more on statistical mechanics and heat transport.
    - *Issues to Consider*: This course is currently a 200-level course in the catalog.
- Physics Electives
    - *Summary*: In addition to the required courses tabulated above students would also have to complete two additional upper-level physics electives. Some possibilities include: astrophysics, computational physics, optics, nuclear and particle physics, simulation and modeling, nanoscience, solid state physics, strength of materials,

an appropriate cognate courses in data science, etc. Another possibility in the fall of the senior year would be to have an "advanced topics" course which covers additional advanced topics in electromagnetism, mechanics, and quantum physics.

- Advanced Lab Techniques I & II
  - *Summary*: I have not fully fleshed out this idea yet, but my thinking is that we reimagine the senior-level *Advanced Lab I & II* sequence as a junior-level hands-on course which covers a wide range of laboratory techniques and methods not previously taught. Some possible topics could include advanced statistical methods, 3D printing, machine shop methods, scientific writing, experimental design, etc. Students could also start to lay out their *Honors Thesis* research proposal.
- Honors Thesis
  - *Summary*: My thinking here is that we allow students the option of carrying out an *independent* research project in their senior year which would culminate in a written Honors Thesis. The department could then award the "best" thesis at the end of the year or at graduation. Note that this sequence would be fully *optional* and perhaps it could be combined with the existing *Honors* program at Siena.

Additional Notes and Thoughts

- It goes without saying that modern physics and computational physics are missing from Table 2 and that there has been a significant reshuffling of the order in which existing courses would be taught. *Although my proposed curriculum isn't necessarily optimal, every change was made for very specific reasons that I look forward to debating!*
- In this proposal the "automatic" math minor is no longer part of the major. However, students interested in graduate school should be strongly encouraged to take linear algebra, applied math, complex analysis, and other upper-level math electives. Alternatively, students can pursue a minor in data science, astrophysics, chemistry, etc.
- In the interest of maximizing allocation of departmental and College resources, I propose we remove *General Physics Review* as a "free" course. One possibility would be to have the students attend one mandatory hour of office hours. The "freebie" *Advanced Lab* contact hours have also been removed.
- There should be a very strong computational thread connecting *all* the courses—and especially the labs. To be specific, we should write down the precise learning goals we want our courses to be able to accomplish (in terms of what we want our students to be able to *do* computationally), and then implement those goals.
- One final thought: a single semester of electromagnetism may not be sufficient, although I'm not sure where a second semester would go.

Proposed Applied Physics BS

The redesigned physics curriculum makes it straightforward to implement an *applied physics* BS, as summarized in Table 3. Moreover, a slight variation in this curriculum will much more easily allow our students to transfer to RPI/Clarkson to pursue either aeronautical or mechanical engineering as part of the 3/2 program, and should also allow our students to pursue the masters in mechanical engineering at Clarkson as part of the 4/1 program.

To avoid double-counting, in this table I have only highlighted the *additional* faculty contact hours (above and beyond the nominal BS) that the new major would require.

Table 3:: Proposed Applied Physics BS Curriculum

Fall Year 1	CH	FCH	**Spring Year 1**	CH	FCH
General Physics I	4	-	General Physics II	4	-
Math for Physicists/Engineers I	1	-	Math for Physicists/Engineers II	1	-
Calculus I	4	0	Calculus II	4	0
Software Tools for Physicists	3	-	Solidworks / CAD	1	1
Total:	*12*	-	*Total:*	*10*	*1*
Fall Year 2	CH	FCH	**Spring Year 2**	CH	FCH
Electromagnetism I	4	-	Mechanics I	4	-
Math for Physicists/Engineers III	1	-	Math for Physicists/Engineers IV	1	-
Calculus III	4	0	Differential Equations	3	0
Chemistry I	4	0			
Total:	*13*	-	*Total:*	*8*	-
Fall Year 3	CH	FCH	**Spring Year 3**	CH	FCH
Advanced Lab Techniques I	1	-	Advanced Lab Techniques II	1	-
Mechanics II	3	3	Thermal Physics	3	-
Electronics I	4	-	Solid State Physics	3	3
Total:	*8*	*3*	*Total:*	*7*	*3*
Fall Year 4	CH	FCH	**Spring Year 4**	CH	FCH
Strength of Materials	3	3	Experimental Techniques	2	-
Honors Thesis			Honors Thesis		
Total:	*3*	*3*	*Total:*	*2*	-

	CH	FCH
Grand Total:	**63**	**10**

Description of Proposed Courses

- Solidworks / CAD
  - *Summary*: Although we already offer a *Solidworks* course, the scope should be expanded to include CAD so it can be used to satisfy the *Engineering Graphics and CAD* course at RPI, which is an important part of many/most of their engineering programs.
- Mechanics II
  - *Summary*: The goal of this course would be to supplement the material taught in *Mechanics I* to include additional content and problems from rigid-body dynamics and statics, continuum mechanics (waves, stress and strain), and fluid mechanics. Together, the *Mechanics I & II* sequence should satisfy *Engineering Dynamics* (ENGR2090) course at RPI and the *Statics* (ES220) and *Rigid Body Dynamics* (ES223) courses at Clarkson.
- Solid State Physics
  - *Summary*: Nearly every undergraduate engineering program includes a course in material science (and we already have a solid state physics course in the catalog, PHYS430). This course should satisfy the *Materials Science* (ENGR1600) course at RPI and the *Materials Science* (ES260) course at Clarkson.
- Strength of Materials
  - *Summary*: This course should satisfy the *Strength of Materials* (ENGR2530) course at RPI and the *Strength of Materials* (ES222) course at Clarkson.

Additional Notes and Thoughts

- One question is whether the combination of our general physics curriculum (including the laboratory component) together with the *Math for Physicists/Engineers* sequence is sufficient to satisfy the *Introduction to Engineering Analysis* (ENGR1100) at RPI.
- Another question is whether our applied physics majors need an additional course in advanced thermodynamics, heat transfer, or fluid dynamics. Clarkson appears to have several courses along these lines as part of their undergraduate mechanical engineering curriculum than RPI, so perhaps there's wiggle room.
- Finally note that the applied BS program (as proposed) requires just one additional credit-hour above the nominal physics BS (and both require nearly two *fewer* courses than the current curriculum!).