Caltech Core Curriculum Task Force:
A Roadmap for Caltech Curriculum Reform
5 December 2010

Executive Summary

We recommend adopting an explicit philosophy for Caltech's core curriculum to make it better serve the needs of Caltech students. Keys to this philosophy are choice for the students and tracks through the core that acknowledge that students vary widely in their previous exposure to individual fields.

The sample future core curriculum outlined in this report fulfills these philosophies and can be implemented with minimal disruption to the students and faculty. It emphasizes critical writing, exposure to new fields, and interaction with the faculty.

Hand-in-hand with this reform must be an increased emphasis on the quality of the core curriculum: modifying courses that no longer meet their goals and either improving or reassigning faculty who do an inadequate job of teaching core courses. We recommend empowering the current standing committees that oversee the core so that they can both implement a reformed core and monitor its progress.

The flexibility of the reformed core provides ongoing opportunities to change individual courses, or even numbers of required courses, based on student and faculty experience. Thus, the reformed core should be viewed as a first step in an evolutionary process of curriculum reform.

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Purpose of the Core Curriculum Task Force

The Report by the 2007 Committee on the Caltech Student Experience and Student Affairs explicitly recommended a review of the Caltech core. The Report stated:

> *The Core Curriculum should be reviewed for content and breadth. In reviewing the Core, the Committee recommends that the undergraduate program have sufficient flexibility to allow students to participate in academic-year research and to provide opportunities for freshman to interact directly with faculty. The review should also consider the range of backgrounds of incoming students, the scheduling of the Core courses, and the use of grades in the third term of the freshman year.*

Charge of the Core Curriculum Task Force

The Core Committee Task Force was formed in response to that recommendation. The charge to the Task Force from the Faculty Board was as follows:

> *The Core Curriculum comprises the Institute requirements for undergraduates for all options and is a defining feature of the Caltech undergraduate experience. A recent study of the Student Experience at Caltech made a convincing argument that a rethinking of the current Core is in order. The Ad Hoc Core Curriculum Task Force will define the purpose and goals of the Core, the desired learning outcomes (what students learn from the Core), and a process by which the success of the Core Curriculum can be assessed. The committee will report their conclusions to the Faculty Board along with recommendations for energizing the curriculum through new content and/or approaches. It is expected that to achieve these goals extensive internal and external consultation will be required.*
>
> *The scope of the committee's deliberations should include, but need not be limited to:*
>
> 1. *Formulating the learning outcomes associated with the core curriculum and specifically investigating the possibility that there be a more flexible core that does not require that every student have the same knowledge but that they prepare for each field in similar fashion;*
> 2. *Recommending curricula (and how to deliver them) that will support the learning outcomes, with specific attention to how we may capitalize, in a way we have never done before in the Core, on the research orientation of the faculty;*

3. *Defining mechanisms to assess the level of student achievement (breadth and depth) and the quality of the student experience;*
4. *Recommending ways of improving professorial teaching in the Core;*
5. *Recommending ways that research and/or independent activities can be brought into the curriculum at the earliest stages of the Core Curriculum;*
6. *Recommending ways of optimizing student/faculty interactions (class attendance and mentoring/advising)*
7. *Considering a restructuring of the academic calendar to improve how the students go about their education and to enhance the student experience;*
8. *Recommending other changes or innovations to strengthen the Core Curriculum experience, such as trial courses, technology in the classroom, or variations in the pass-fail grading system.*

The committee has interpreted these charges as asking:

1. *What should a student learn in the core?*
2. *What classes should be taught?*
3. *How do we know it is working?*
4. *How can we make sure it is taught well?*
5. *Can research be brought into the core?*
6. *Can we increase student-faculty interaction?*
7. *Should we switch to semesters?*
8. *Is there anything else we should be doing?*

The following report is our response to these questions.

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The Purpose of a Core

The first question that should be considered before considering changes to the core is: should there even be a core? Few other educational institutions attempt a scientific core. Most rely instead on distribution and option requirements to guide student course selection. Yet in surveys of Caltech faculty, students, and alumni, the answer to the question of whether or not Caltech should have a core is an overwhelming "yes." Not everyone necessarily agrees on what the core should be or even why it should be, but there is extremely strong support throughout the community for maintaining a core. The sentiment is often expressed that "Core is what makes Caltech special;" however, there is no general agreement on what it is about the core that makes Caltech special. Nonetheless, the Task Force took this strong support to justify the boundary condition that Caltech should have a core, and as a mandate to make certain that the core is indeed something that does make Caltech special.

Given a core, the next important question, the answer to which should then drive every subsequent decision to be made, is simple: what is the educational point of the Caltech core?

In discussing this question among the committee and with students, faculty, and alumni, we heard five main factors that motivate a core:

<u>Depth</u>. The core should give students a substantial working knowledge of the basics of all of the important areas of science.

<u>Breadth</u>. The core should cover a broad range of scientific disciplines. Students should emerge with sufficient background to understand or teach themselves about most scientific issues.

<u>Exposure</u>. The core should give students enough insight into each field that they can make informed decisions in selecting their major at the end of the core and still complete their degree in four years of study.

<u>Bonding</u>. The core should give all students the same experience, thus forging connections that will serve them for their years at Caltech.

<u>Utility</u>. The core should include only classes that are needed as common prerequisites for all majors. Students should learn material that might help them in the disciplines on which they ultimately choose to focus.

Caltech now implements an inconsistent mixture of these five goals. The current core tries to teach much of the important knowledge in some fields while giving only a preview of other fields. It is worth noting that these strongly voiced goals are somewhat inconsistent, and that the current implementation of the core and the individual graduation requirements of some of the most requirement-rich majors make it challenging, if not impossible, for the core to achieve all of them.

Although students eager to start in their chosen field (and motivated faculty in individual options) could argue that the core should prioritize Utility, this philosophy essentially eliminates the core: if the core requirements are only what your prerequisites would be otherwise, you might as well have no core requirements. If we front-load the curriculum with requirements for individual majors, we would challenge the Exposure motivation for the core. It is possible that there is no core that would satisfy the Exposure imperative for all majors.

Many options offer alternative core classes for those intending to pursue them, and the reports from all have been that these both serve the needs of their majors and the goals of the core. We take the success of these core-alternatives as a strong indication that the core experience need not be a unitary one, with all students moving through the same courses in lock step.

In our opinion, it is significantly more important to train students in a broad range of important basics that allow them to teach themselves new things when needed than it is to teach them everything. We thus feel that the design of the core should follow most closely the Breadth philosophy. The Caltech core, then, becomes a “liberal science” program, that is, the scientific counterpart of a traditional liberal arts education. The purpose of a liberal arts education is not to teach the student a defined set of specific topics but rather to teach the student how to think about, learn about, and understand all aspects of society. This goal is met by exposing a student to a wide range of classes in a variety of disciplines.

Most undergraduate scientific educations focus narrowly on their field of expertise (while usually having distribution requirements outside of their chosen field and outside of the sciences). A student receiving such an education is not learning how different scientists across different disciples think, but rather being trained to be a specialist in a specific discipline. In contrast, a “liberal science” education would teach a student how to think about, learn about, and understand all aspects of science. In a world in which science is increasingly inter-disciplinary and in which science of all sorts is increasingly intertwined with society, such an education would be increasingly valuable. Such a broad scientific education would also be unique among universities, and it could truly be part of what makes a Caltech undergraduate education special.

This philosophy for the core is not significantly different from that stated in the current Caltech catalog:

> *A Caltech education requires not just the depth of an option but also considerable breadth in basic science, humanities, and social science. Caltech's core curriculum prepares students for the interdisciplinary nature of contemporary research in science and technology. This encourages a culture of problem solving,*

> *collaboration, and communication while providing valuable experience in all fields of science. Significant study in the humanities and social sciences is an important component of Caltech's core curriculum, giving alumni the ability to navigate the societal, political, and economic factors, that influence, and are influenced by, their work.*

Indeed, a similar philosophy was endorsed by Noyes, Millikan, and Hale, who suggested that a Caltech education should

> *… include an unusually thorough training in the basic sciences of physics, chemistry, and mathematics, and a large proportion of cultural studies… It is hoped in this way to make the undergraduate courses of the Institute a combination of the fundamental scientific training with a broad cultural outlook.*

Proposed philosophical changes to Caltech core

Based on the above considerations, we propose six major philosophical changes to how we approach the core. Combined with a faculty commitment to high quality undergraduate education, we believe these changes could significantly reenergize education at Caltech.

1. Renormalization of requirements across the key sciences

Math, physics, and chemistry have always been the important foundational aspects of the core. More recently biology was added. In reexamining these key foundations in light of our overall core philosophy, we believe that while math, physics, chemistry, and biology remain critical, several modifications are in order. As part of the goal of breadth, we deem the current core, which creates, for example, physicists who know a little bit about biology and biologists who know much more about physics, to be less ideal than a core that creates physicists who have had a broad exposure to biology in addition to biologists who have had a broad exposure to physics. We thus recommend a renormalization of the requirements across the key sciences.

2. Choices throughout the core

The goal of the core is for every student to acquire and be able to build upon a foundation in key areas while also being exposed to disciplines across the sciences, engineering, and humanities. Currently, Caltech attempts to achieve this goal by requiring the majority of students to take a certain set of classes. This approach poses some serious difficulties. Even at an institution like Caltech, students arrive with a wide variety of pre-college experiences and abilities. Attempting to place these students into a small number of classes leads, inevitably, to some students having classes over their heads and others coasting through classes which are below their level of preparation.

The current solution to students being put in classes over their heads is to make the first two terms pass-fail, thus giving less-prepared students time to catch up. While these students may do poorly in core classes the first two terms, their initial floundering does not penalize their GPAs. But while their GPAs are not penalized, their education is. No educator would suggest that struggling in a class that is more advanced than one's level of preparation is an appropriate way to learn. Instead, the wide variety of abilities amongst incoming students demands a wide number of potential paths for satisfying the core requirements. While every student should acquire a deep foundation in key areas and breadth across disciplines, the manner in which these are acquired should be considerably more flexible and tuned for the range of abilities of the Caltech undergraduates. We believe that one of the most important philosophical changes to the current core is to allow choices throughout the mandatory core requirements.

Indeed, we believe that flexibility and choice at as many junctures as possible – rather than prescribed classes and few options – will drastically improve the student experience. If choices exist throughout the core, a student need not feel oppressed by any particular required aspect of the program.

3. An intensive emphasis on critical writing skills

The development of critical writing skills is a key area that is missing from the foundational principles underlying our current core. While we traditionally think of science and math as being the only foundational parts of the core, few would argue that critical writing is not equally important. The current core does explicitly require writing intensive classes, but we believe this aspect of the core is sufficiently important that it should be philosophically elevated to the same level as science and math. We therefore recommend an intensive emphasis on critical writing skills in courses both in and out of HSS.

4. Early exposure to more faculty in non-lecture settings.

Adding more flexibility to the core also allows us the opportunity to exploit one of Caltech's unique aspects: its student-faculty ratio. No institution has a lower student-faculty ratio, yet most incoming students have no opportunity to take advantage of this aspect of Caltech except in HSS classes. Students arrive at Caltech excited by the possibilities of working closely with world-class scientists, engineers and mathematicians. Such excitement is best built upon by exposure to and interaction with faculty, not by large lecture classes and endless problem sets. We therefore recommend exposure to faculty in non-lecture settings as a part of the core.

5. A commitment to improved labs involving data collection & analysis and design & build

What students learn at Caltech ultimately involves describing, measuring, and/or manipulating things in the real world. As part of the core experience it is thus critical for students to learn how to deal with the real world. Lab classes provide this exposure to reality. Labs require dealing with real world issues such as laboratory techniques, time management, and data interpretation/analysis, as well as malfunctions, breakages, and errors. Furthermore, labs provide the important role of teaching doubt.

An important part of the proposed core lab experience should be for a student to design something, build it, and make it work. This provides exposure to a different and equally critical aspect of the real world, namely the tradeoffs that have to be made between what is desired, the time/money/hardware/skills available, and the underlying scientific feasibility.

We propose that the Institute take undergraduate labs much more seriously by investing significant new resources in lab classes, as we believe that Caltech labs are now underfunded and under-appreciated compared to labs at other institutions.

6. Exposure to new intellectual frontiers

The core is crafted much as it might have been a few decades ago, before the emergence of informational and computational approaches. As a result, it does not teach now-important subjects such as algorithms. Over the last six decades, algorithms have transformed science and engineering, yet the current Caltech core gives no hint of this transformation. Every Caltech undergraduate should be introduced to such new frontiers: we particularly urge that it include the analysis, implementation and application of algorithms in the information, biological and/or physical sciences.

7. A commitment to innovative courses and excellent teaching.

The Caltech core has involved some of the best lecturers over the history of the institute; however, without adequate attention to quality and innovation, it is far too easy for even the most famous courses to become a shadow of their former selves. During the course of the committee's work, a number of courses were noted that were no longer meeting their goals. In less than a year, three of these courses transformed themselves from courses that generated student complaints to courses that are receiving praise. Such stories offer ample evidence that evaluation and oversight, together with faculty willing to enact change, can result in superior course offerings.

We propose that the campus build upon the recent investments in course innovation to create formal efforts in course evaluation and course improvement. Empowering the cognizant committees with oversight over course performance is an important first step. Recent efforts at video recording courses show that it provides an important source for self-improvement and assessment of the faculty. In addition, recordings of all the lectures in a course can offer faculty an important teaching tool. The committee endorses the course assessment and video-recording efforts underway. We propose that the campus fully embrace them, providing yearly assessment of each core course and supporting the costs of video-recording up the entire course for those faculty that desire such recordings.

Two other important considerations also drive our considerations of the core. First, we believe it is an important goal that any new core have no more units than the current core; indeed, a smaller core would be desirable to give students the ability to make more choices throughout their time at Caltech. Second, we think that it is vital that any new core at Caltech not increase the teaching load per faculty member, option, or division. With these philosophical underpinnings, we will propose a vision of what such a reformed core might look like in the future.

A Reformed Core.

Given the philosophy developed by the committee, the feedback provided by the faculty survey, and the feedback provided at meetings with students, the faculty, and the Faculty Board, we have constructed a reformed core curriculum. In the following, we provide an overview of the proposed core requirements, followed by a description of its components and a discussion of the issues to be considered in implementing the proposed courses.

Overview of the Reformed Core requirements:

Freshmen seminar (1 term)

Physics (4 terms)

Math (4 terms)

Chemistry (2 terms)

Chemistry Laboratory (1 term)

Biology (1 term)

Breadth menu (1 term)

Programming (1 term)

Algorithms (1 term)

Design & Build Laboratory (1 term)

Writing-intensive freshman humanities (2 terms; graded)

Writing-intensive advanced HSS classes (4 terms; graded)

HSS electives (combined with the writing intensive classes to a total of 11 terms)

Freshman seminar

A Freshman Seminar (FS) involves a small group of students interacting directly with a faculty member to study a topic of the faculty member's choosing. The FS offers a simple way to increase the direct contact between students and faculty, early in each student's time at Caltech, and provides an opportunity for each student to explore novel areas outside of the normal core requirements. At universities that do them well, such as Princeton or Harvard, the Freshman Seminar has been a very positive experience for both faculty and students.

We propose FS as a required, first-term course, in which 10-15 freshmen and a single faculty member explore in depth an exciting topic in the lab, around a table, in the field, or anywhere else appropriate. The topic of the FS need not be in the area of faculty expertise; indeed the students might get the best experience from watching how a faculty member attacks a novel problem. Examples that have been suggested by a variety of faculty members include looking for signatures of the ice age glaciations in Southern California, exploring the physics of music, and reproducing important classical experiments in a given field. We believe that the Caltech faculty are sufficiently interesting and creative that everyone could imagine one or two such seminars that they might enjoy teaching. The Frosh Seminars are not intended to be a requirement for SURF-type individual research, though, done well, such research could work well as such a Frosh Seminar.

We believe that Freshman Seminars would not only advance our core philosophical goals, but would also be an important move to dramatically change the incoming student experience. They would offer our entering students, when they are at their most energized, the opportunity to do much more than sit in lecture halls. The FS would immediately channel the students' excitement and curiosity, while also allowing them to build a relationship with at least one faculty member, and giving them an experience that could become known as a defining feature of Caltech.

<u>Proposed Freshman Seminar Policy</u>

All freshmen shall take a Freshman Seminar (6 units) in their first term.

Enrollment will be limited to first term freshmen, as the experience will be altered by mixing in more advanced students.

<u>Potential Implementation issues.</u> *Freshman Seminar requires that a set of courses be solicited, evaluated, and approved so that students can have a list from which to select. Based on the programs elsewhere, we suggest that proposals be solicited in the fall term, due in the winter term and be approved and posted in the spring term. The Core Curriculum Steering Committee, the Curriculum Committee, and/or a special subcommittee of either would be the logical channel for the approval process. Other such programs have identified contact committee members in each discipline to help advise the proposing faculty.*

Each Freshman Seminar should be evaluated periodically to assess quality and to make sure that there is not a huge mismatch in workload between offerings.

Physics Core

The current physics core offers a chance for students to learn a systematic approach to attacking problems, through the three terms of Ph1a,b,c and then be immersed in more modern physics through Ph2a,b. The previous revision of the core shortened the core physics requirement from six to five terms, challenging instructors to present a full core in less time. The experience of the past few years argues that a workable solution has yet to be identified. We propose that the intention of the physics core would best be accomplished by the three terms of Ph1 and a fourth term from a menu of offerings that present some advanced topics or a survey course such as "modern physics." Survey courses seem to be frowned upon by many, but are efficient capstone courses for students who will not go on to take more advanced courses in that area. The one term menu requirement will involve stand-alone courses that eliminate the challenge of presenting more material than conveniently fits into the current two terms.

Proposed Freshman Physics Core Policy.

All students shall take four terms of physics as a core requirement.

Students will take one of the offered paths through Ph1, and will satisfy the fourth term of physics core by selecting one course from a menu of offerings.

Potential Implementation issues. We anticipate that many options will require physics beyond the core requirement, and students might take extra physics as part of their science electives. It is hoped that the replacement of Ph2a,b with a menu selection will result in a variety of courses being offered, including some courses from outside of the PMA division. The CCSC and/or the Curriculum Committee will need to develop ties with the EO of Physics and perhaps other options to coordinate offerings.

Math Core

The math core offers a chance for students to learn math proofs and the basics of calculus, linear algebra and vector calculus through the three terms of Ma1a,b,c, and then be immersed in Differential Equations and Probability & Statistics through Ma2a,b. Ma1a has been refined this year to better introduce proofs to students with more limited background, with great success. Students who would like to move through the curriculum of Ma1 more deeply can take a special section of Ma1a, followed by Ma1d, a 5-unit course the next term. Some have suggested that there are more students who would benefit taking Ma1d.

The experience of the past few years argues that there is room to refine the math core. While there is interest in both Ma2a and Ma2b, it appears that different options have different needs from Probability and Statistics. In addition, a growing number of students are taking ACM95 and Ma2a, suggesting there may be ways to repackage the material to best meet the needs of students who will go on to take ACM95.

Proposed Freshman Math Core Policy.

All students shall take four terms of math as a core requirement.

Students will take one of the offered paths through Ma1, and satisfy the fourth term of the math core requirement by selecting one course from a menu of offerings.

Potential Implementation issues. *It is anticipated that many options will require math beyond the core requirement, and students might elect to take extra math as part of their electives. It is hoped that the replacement of Ma2a,b with a menu selection will result in a variety of courses being offered, including courses that might more specifically meet the needs of the students in certain options (e.g. Probability and Statistics for Genomics Research), and perhaps including some taught by options from outside of the PMA division. The CCSC and/or the Curriculum Committee will need to develop ties with the EO of Math and perhaps other options to coordinate offerings.*

Chemistry

The chemistry core is intended to present a foundational knowledge of chemistry using lecture and lab courses. In the previous revision of the core, the chemistry core was compressed by the elimination of one term of chemistry, resulting in Ch1a (6 units), Ch1b (9 units) and a required lab, Ch3a (6 units). Recently, the CCE division has revitalized Ch3a and is developing a variety of specialized Ch3 courses with different areas of specialization. CCE has also developed a powerful way to provide support for students more advanced or less advanced than the typical freshman. This provides an excellent mix of choice and support for the students.

Proposed Freshman Chemistry Core Policy.

All students shall take two lecture courses: Ch1a (6 units) and Ch1b (9 units).

Students desiring a more advanced version of Ch1a can elect to take a 3-unit expansion of the course.

Students desiring a more complete version of Ch1a, due to a limited background in chemistry, can elect to take a different 3-unit expansion of the course.

All students shall take a freshman chemistry lab, selected from Ch3a (6 units), or one of the new versions of Ch3a, such as Ch3x or Ch3y.

Potential Implementation issues. *The CCE Division has done an admirable job in developing a multi-path trajectory through the chemistry core requirement. The appendix contains a full description of the chemistry core.*

Biology

The Faculty Survey, the previous Core Curriculum Committee and the CCTF all argue that biology is a field that must be represented in the core. How it is represented can vary widely, but there are basic concepts in modern biology to which all of our students should be exposed, including basic molecular biology, genomics and evolution. In recent years, there have been a few different implementations of the Bi1 core course that each introduced these basic concepts via topical subjects such as the origin of life, drugs and the brain, or the biology/biophysics of viruses. In addition, a B1X has been developed that introduces the core concepts of biology in an integrated lab-lecture format. We endorse these and other implementations, and propose a core biology requirement of Bi1 or one of its variants such as Bi1X.

<u>Proposed Freshman Biology Core Policy.</u>

All students shall take one of the approved Bi1 courses (9 units).

Students may substitute Bi8 (molecular biology) or Bi9 (cell biology) for the core class (but they will not be considered “core” for P/F rules established below)

Non-biology majors may also substitute a more advanced biology course for the core requirement if they received a 5 on the Biology AP exam and if they petition the Biology option representative for approval (but this substitution will not be considered a “core” class for the P/F rules established below).

<u>Potential Implementation issues.</u> The Core Curriculum Steering Committee will need to monitor the performance of the various Bi core courses. The CCSC should encourage the proposal of additional variants of the core courses from divisions outside of Biology, in more interdisciplinary areas such as biochemistry, biophysics, or geobiology (so long as the courses present the core materials related to molecular biology, genomics and evolution).

Breadth menu courses

The breadth menu in our reformed core continues the current Menu requirement. We believe that the philosophy behind the current Menu, i.e. exposing students to areas outside of the generic core, is well supported by the Faculty Survey and recent experience with the Core.

<u>Proposed Freshman Breadth Menu Policy.</u>

All students shall take one of the approved Breadth Menu courses (9 units).

<u>Potential Implementation issues.</u> The CCSC should continue to support the development of new menu classes. The CCSC should monitor the workload and difficulty of each Breadth Menu course to keep them uniform across the offerings.

Basic Programming

Every Caltech student should have basic programming skills. We propose that students should take (or pass out of) a basic programming course during the very first term at Caltech. The goal here is not to require students to learn advanced programming concepts, but rather to bring every student up to a basic level of competence that can be further developed by exercises in the other core courses. The new implementation of CS1 has proved popular with students, is working well, and can serve as the model for the Programming Core requirement.

We recommend that instructors include computational problems in many of the core or all of the core classes. Since after implementation of the new core, instructors will be able to assume a minimal level of competency, they could assign such problems without having to worry about teaching remedial programming. Continual exposure to such problems would give students critical practice and allow them to become comfortable applying these tools in all aspects of their education and research.

Proposed Freshman Programming Core Policy.

All students shall take CS1 or an approved equivalent course (9 units).

Potential Implementation issues. *The CCSC should encourage the expansion of CS1 or the formation of a few variants to avoid the class from becoming too large to effectively teach.*

Algorithms

Modern science and engineering rely on three pillars: theory, experiment and computation. At present, the Core exposes the students to only two of these three pillars. The proposed algorithms requirement will introduce Caltech undergraduates to the analysis, implementation and application of algorithms. Students could satisfy the requirement by taking one of a menu of courses that would introduce fundamental concepts and inspiring applications of algorithms in the information sciences, life sciences, and/or physical sciences. The details of three proposed Algorithms Core Courses are presented in the Appendix.

Proposed Algorithms Core Policy.

All students shall take one of the approved Algorithms Core Courses (9 units).

Potential Implementation issues. *The Algorithms Core courses will be new and may require support to be developed. Special attention should be paid to the student performance and workloads of these core courses so corrections can be made.*

Design and Build Lab

As argued in our philosophy statement, lab experiences are key to the development of our students. Ch3 represents an important part of chemistry instruction and presents key lessons in lab safety and data analysis. We believe, however, that students need a second lab experience in the form of a Design & Build Lab hat will give them a chance to build a tangible object (either hardware or wetware). This requirement should be met by a variety of different choices, allowing students to select the experience most relevant to their interests.

<u>Proposed Design and Build Policy.</u>

All students shall take one of the approved core design and build labs (9 units) that permit them to design and construct a tangible object or device. Courses relying solely on programming or virtual objects will not meet the core requirement.

<u>Potential Implementation issues.</u> The set of Design & Build Labs will require a renewed investment in the lab facilities on campus and will require an annual supply investment that is likely to be ca. $1,000 for each enrolled student.

Humanities and Social Science

Caltech should maintain its strong commitment to the humanities and social sciences. It is essential that students moving out into world of science and technology understand the human societies in which they will be working and which their work will impact. It is equally important that they be able to communicate to others what their work is about and why it is important, whether it be to committees in charge of grants, legislators controlling government research appropriations, or members of the general public who want to understand science and its conclusions. Caltech students therefore need to take as many courses as is reasonably possible in history, literature, philosophy, and ethics, as well as in economics, political science, law and anthropology. In order to avoid making the new core larger than the current one, however, and in line with our goal of reducing the number of absolute requirements in any one area of the core, we propose that the number of required HSS courses be cut from 12 to 11.

Humanities classes are particularly important for implementing the proposed core's emphasis on critical writing skills. Our proposal, therefore specifically calls for increasing the number of writing intensive courses in the HSS part of the core from the current four to six. Two of these courses will be the freshman humanities courses. We urge the HSS Division, however, to make it possible for the remaining four courses to be taken either in the humanities or in the social sciences, rather than exclusively in the humanities as is currently the case. In addition, we suggest that the current distribution requirement in the HSS part of the core (two advanced courses in H and two in SS) be dropped. These two changes together will allow students to focus their advanced HSS courses, or not, as they choose, once they have satisfied the breadth requirements associated with the frosh hums and intro social science courses.

We also propose requiring that the writing intensive courses in the HSS part of the core be taken for grades, regardless of when they are taken. Too many Caltech students currently take advantage of the P/F regime in the freshman courses, or choose to take advanced courses P/F, to avoid having to work on their writing more than the minimum amount required to pass. As a consequence, their writing does not improve. The humanities faculty do not have the leverage they have in graded courses to get such students to work on their writing. They often, therefore, get frustrated as they see their efforts wasted. Requiring letter grades in the writing intensive HSS courses will promote more effective writing instruction by assuring that the courses receive the attention from the students that they deserve and by giving the HSS faculty the assurance that their efforts will be taken seriously.

Proposed HSS Core Policy.

All students shall take eleven HSS courses (9 units each)

Six of the HSS courses must be writing intensive and taken for a letter grade.

Students will take two Frosh Hums and two Introductory Social Science courses, but are free to shape their own HSS curriculum with no concentration or breadth requirements.

Potential Implementation issues. *The HSS requirement is an important part of the Caltech experience and deserves more attention from the students and faculty. The CCSC, working together with the HSS Division will need to set the standards that make a course considered writing intensive. The CCTF believes that a single writing project, assigned at the end of the course, does not meet this standard.*

Tied to this proposal is a concern that the institute invest adequately in the operation of a writing center. The current Hixon Writing Center has laudable goals, but seems underfunded and overworked. Given that good writing is a key aspect of the careers of all of our students, it will be wise to make an expanded version of the Hixon Writing Center an institute wide priority. In particular, it should be re-imagined and re-configured so that it serves the entire campus community, in all divisions, rather than its current implementation as an adjunct to the HSS writing course. As such, it may be best to move its financing and operation away from the HSS Division.

Writing Across the Institute

Given the importance of writing in publications, proposals, and patents, writing proficiency should be required of our students in more than HSS courses. This requirement should go beyond the current science writing and communication requirement. The latter is aimed at teaching the students particular styles of writing and oral presentation associated with the particular disciplines in which they are concentrating. We believe that students need to write in the context of doing coursework in science, engineering, and mathematics. Only this, we think, will drive home to them the lesson that writing is not just something they do to satisfy their HSS requirements, but something they will need to do, and do well, in all aspects of their future careers.

In response to this imperative, we propose a new program: Writing Across the Institute. Not all Caltech classes need or should be writing classes, but we believe that the more widely-spread writing is taught in the Institute, the better our students will become at this crucial skill. In its discussions of this issue, the CCTF considered several ideas, including having all options require a senior thesis, or implementing a total writing unit requirement that students would satisfy partly with HSS courses and partly with courses in other divisions. Though each of these ideas has its own merits and weaknesses, we decided in the end that the simplest would be to require each student to take some minimum number (two or more) writing intensive classes outside of the HSS division, as well as the separate class that fulfills the science writing and communication requirement (see below).

Any class wishing to be considered writing intensive would need to contain a minimum number of writing assignments. We propose developing uniform standards on the amount of writing, and the nature of the feedback and rewriting that would be required for writing requirement with the help of the Humanities faculty, who have had significantly more experience in writing instruction than most of the rest of the faculty.

<u>Proposed Writing Across the Institute Policy.</u>

All students shall take some number of their non-HSS courses (two of more) selected from a listing of courses that qualify as writing intensive.

<u>Potential Implementation issues.</u> The CCSC and Curriculum Committee would need to establish standards by which a course can be considered writing intensive, and periodically review the courses to assure that this feature remains in place in the course.

Courses approved as writing intensive would need some signification, such as an added letter in uniting, to signify that the course could be used to meet the writing intensive course requirement (for example, Bi/BE177 (6-0-6-w)).

The Hixon Writing Center can play a large role in the creation and instruction of writing intensive courses, if it is expanded as proposed above.

Science writing and communication

The science writing and communication requirement grew from the perception that science writing was not being adequately taught at Caltech, and that particular disciplines had correspondingly particular traditions of writing and oral presentation to which their students needed to be exposed. Through more than a decade of experimentation, a few very good courses have appeared that offer students active instruction in science writing and communication. However, there are also some courses that meet the spirit of the requirement in name only. We endorse the successful courses that have been developed and ask that these positive examples be used as models for all courses. At present, these courses are an institute requirement, but not formally a part of the core. We propose that they be brought under the same oversight as the core courses. In addition, we urge that these courses be made substantive 9 unit courses that incorporate multiple revisions of one or more writing projects, rather than a single, terminal paper. The courses will, as now, be developed and run by the individual options.

<u>Proposed Science Writing and Communication Policy.</u>

All students shall take a Science Writing and Communication course in their option (9 units).

<u>Potential Implementation issues.</u> The CCSC and Curriculum Committee need to establish standards for the Science Writing and Communication Courses, and periodically review the courses to assure they are meeting the standards.

Pass-Fail Policy

The CCTF obtained a large amount of input on the current policy of the first two terms of pass/fail (P/F) grading. P/F grading has the positive effect of easing the transition to Caltech classes and minimizing competitive interactions between students. However, P/F also has its dark side: it permits core courses to be designed without fully considering the preparation of the students; it motivates a few students to overload in their first two terms to take advantage of the P/F status; it might foster a lazy style of working on course material until it is “good enough” for the P. It was this final issue that led the previous committee that evaluated the Core Curriculum to abolish P/F in the third term. In interviewing students and faculty, the CCTF found many examples in which student performance and faculty morale were adversely affected by the present P/F policy. This has particularly affected the quality and quantity of writing intensive classes on campus, as students are not incentivized to improve a writing project through interaction with the faculty.

Input from many students argued that reducing P/F to less than two terms could have negative effects on cooperative interactions between students. Countering this is the lack of a change in student interactions when the third term was moved to grades from P/F. Other students have argued that eliminating P/F would decrease their ability to take exploratory courses that would be too risky to take on grades. Countering this are the many stories the CCTF heard from faculty about advisees that overcommitted themselves because of the motivation of P/F in the first two terms, often by enrolling in classes that were obviously far too advanced for their level of preparation.

Balancing the potential good and potential bad of a P/F policy, the CCTF recommends the following narrowing of the policy:

Proposed Pass/Fail Policy

All classes in the first term will be pass/fail.

All core classes in the second term will be pass/fail.

Courses substituted for core requirements in the second term will not be P/F automatically.

Any writing intensive class taken in any term will be taken for a letter grade.

Potential Implementation issues. Some have argued that this policy will decrease the opportunity for students to explore in their first two terms; however the CCTF feels that students in their first term or two are best served by policies that encourage lighter course loads. Thus, the freshman advising system and the Dean's office should set a very high bar for permitting students to overload.

If a student wishes to take an exploratory course in their second term, they would be free to use one of their individual P/F slots, so the new policy will not be a disincentive for exploration.

The CCTF notes that the CCSC and the Dean's office will need to monitor the use of P/F by the students, and it strongly recommends that a "core only" P/F policy be adopted if there is any evidence that the policy is being used to "game" the system by taking inappropriate courses in the first term.

Appendices

Size of the Reformed Core

The goal of the CCTF was to rebalance and improve the core, without an increase in the size of the core. The tables below present the Reformed Core and compare it with the current core.

Typical Schedule - Current Core

Freshman Year					
FA (P/F)		WI (P/F)		SP	
Ma 1a	9	Ma 1b	9	Ma 1c	9
Ph 1a	9	Ph 1b	9	Ph 1c	9
Ch 1a	6	Ch 1b	9	Bi 1	9
Ch 3a	6	Intro Lab	6	Menu	9
Fr Hum	9	Fr Hum	9	HSS	9
PE	3	PE	3	PE	3
TOTAL	42		45		48

Sophomore Year				Remaining Courses	
FA		WI			
Ma 2a	9	Ma 2b	9	Sci Writing	3
Ph 2a	9	Ph 2b	9	Sci Presenting*	3
HSS	9	HSS	9	HSS	63
TOTAL	27		27		

Typical Schedule - New Core

Freshman Year					
FA (P/F)		WI (P/F Core)		SP	
Ma 1a	9	Ma 1b	9	Ma 1c	9
Ph 1a	9	Ph 1b	9	Ph 1c	9
Ch 1a	6	Ch 1b	9	Bi 1 Menu	9
Fr Seminar	6	Ch 3 Menu	6	Breadth Menu	9
CS 1	9	Fr Hum	9	Fr Hum	9
PE	3	PE	3	PE	3
TOTAL	42		45		48

Sophomore Year				Remaining Courses	
FA		WI			
Math Menu	9	Physics Menu	9	Sci Communication	9
Algorithms Menu	9	Design/Build Lab	9	HSS	63
HSS	9	HSS	9		
TOTAL	27		27		

The size of the Reformed Core is increased by incorporating a course that almost all students take at present (CS1), by including in the listing a mandate that was previously not listed in the core (Science Writing and Presentation), and by enlarging the number of units for courses that involve extra effort of the student (Ch1a variants). The unit numbers don't acknowledge an important fact: that we have adjusted the content of the courses to make the workload more manageable for the students than the present core. Although the CCTF wishes it could have decreased the number of units of the core, we feel that the flexibility and rebalancing of the Reformed Core permits a full core without overburdening the student body.

Typical Schedule - New Core, Low Preparation

Freshman Year					
FA (P/F)		WI (P/F Core)		SP	
Ma 1a + Ma 8	12	Ma 1b	9	Ma 1c	9
Ph 1a	9	Ph 1b	9	Ph 1c	9
Ch 1a (Remedial)	9	Ch 1b	9	Bi 1 Menu	9
Fr Seminar	6	Ma 1d	5	Breadth Menu	9
CS 1	9	Fr Hum	9	Fr Hum	9
PE	3	PE	3	PE	3
TOTAL	48		44		48

Sophomore Year				Remaining Courses	
FA		WI			
Math Menu	9	Physics Menu	9	Sci Communication	9
Algorithms Menu	9	Design/Build Lab	9	HSS	63
HSS	9	HSS	9	Ch 3 Menu	6
TOTAL	27		27		

New Core			Old Core	
Freshman Mathematics (Ma 1abc)	27		Freshman Mathematics (Ma 1abc)	27
Freshman Chemistry (Ch 1ab)	15		Freshman Chemistry (Ch 1ab)	15
Freshman Chemistry Lab (Ch 3)	6		Freshman Chemistry Lab (Ch 3a)	6
Freshman Physics (Ph 1abc)	27		Freshman Physics (Ph 1abc)	27
Freshman Biology (Bi 1 menu, 8, or 9)	9		Freshman Biology (Bi 1, 8, or 9)	9
Freshman Programming (CS 1)	9			
Freshman Seminar	6			
Math Menu	9		Sophomore Mathematics (Ma 2ab)	18
Physics Menu	9		Sophomore Physics (Ph 2ab)	18
Breadth Menu	9		Breadth Menu	9
Algorithms Menu	9			
Design and Build Laboratory	9		Additional Introductory Lab	6
Science Communication	9		Science Writing	3
			Science Presenting*	3
Freshman Humanities	18		Humanities (2 intro + 2 adv)	36
Intro SS	18		Social Sciences (2 intro + 2 adv)	36
Additional HSS	63		Additional HSS	36
PE	9		PE	9
TOTAL	261		TOTAL	258

** Science writing and communication are not formally counted in the current core curriculum accounting, but are required in every option, making them de facto requirements in the current core.*

Details of Algorithms Core Courses

The goal of the Algorithms Core Courses is to provide Caltech students with an introduction to the analysis, design, implementation, and application of algorithms in the physical, biological and information sciences. The CS faculty, in collaboration with Niles Pierce, have developed three different courses, each with the goal of presenting the interplay between theory, experiment and computation in modern science and engineering. Each are intended to use a modular multi-week organization to investigate classes of algorithms an their application to a set of examples. The planned menu of one-term courses is:

Introduction to Algorithms (prereq: CS 1)

Introduction to Discrete Algorithms (prereq: CS 1)

Introduction to Numerical Algorithms (prereqs: CS 1, Ma 2a)

The following sections outline the courses and their content.

Introduction to Algorithms (Discrete and Continuous)

(Prereq: CS 1) This course introduces students to a wide variety of "Algorithms," interpreted broadly as step-by-step procedures on computers. It includes an introduction to language-based strategies like lexing and parsing, discrete problem solving strategies, network programming as well as numerical computation algorithms in serial and parallel.

I. Introduction to Algorithmic Notions, one week.

- Sorting as example (insertion sort, divide and conquer through merge, asymptotic analysis, notation big-O, etc.)
- Regular expressions, using parsing, lexing algorithms for creating specialized "mini-languages" for the user to interact with computers and increase human programming power.
- Application: NP-completeness as type of "difficult" computational problem

Weeks 2,3,4 Introduction to Algorithmic Problem solving strategies

- Data Structures and Complexity
- Lists and trees, Link between binary search tree sort and quicksort, Hash Tables for insertion,deletion in constant time
- Dynamic and recursive programming. Applications: First contact: brute-force, exponential time algorithm; Saving subsubproblem solutions to accelerate.
- Divide-and-Conquer, Graph algorithms: Shortest path problem, Greedy algorithms
- Applications: Longest substring in DNA sequences, flu virus, computer graphics "Seam Carving" (different type of image resizing algorithm that preserves “relevant” features)

Weeks 5,6. Introduction to Concurrency and Networking Algorithms

Parallel algorithms: Parallelization and Synchronization Locks, to prevent another thread from reading or altering a variable while we are in the process of modifying it ourselves, web-crawling in parallel, finding all links and indexing pages. Parallel-merge, or parallel matrix multiplication, GPU and stream programming.

Network/web algorithms, network programming

Weeks 7,8,9,10: Introduction to Numerical Algorithms

Reality of IEEE Numerics. Floating-point operations vs fixed-point. Not associative, so order is important

Linear algebra algorithms. Conjugate gradient intro. Eigenvalue/eigenvector -> LLE & google-rank, Algorithms for Latent Semantic Analysis. SVD, pseudoinverses

Introduction to continuation methods, to solve nonlinear equations

From Fourier transform to FFT (the divide-and-conquer version)

Simple ODE and PDE Integration: notion of invariance and accuracy, N body problem, Concept of FMM (multipole expansion and related algorithms.)

Applications: google page rank, from pendulum to planet trajectories, N body problem.

Introduction to Discrete Algorithms

(Prereq: CS 1) The course is organized roughly around “algorithmic strategies.” Each module has topics (major examples of the strategy) together with potential programming projects. A secondary goal is to develop general skills relevant to algorithm design, and some of these are explicitly identified in the outline below.

I. Greedy (2 weeks)

Topics: Minimum Spanning Tree, Huffman Coding

Projects: network broadcasting making use of MST; compress different text corpora, use this to discover something interesting like the entropy of different languages

Skills: thinking formally about algorithms and problems; finding counterexamples (where greedy fails)

II. Divide and Conquer (2-3 weeks)

Topics: sorting (quicksort, mergesort), Strassen’s algorithm for matrix multiplication, FFT and possibly fast wavelet transform

Projects: implement Strassen and experiment to find crossover point -- discover cache effects; image compression by discarding high frequency components

Skills: asymptotic running times; recursion and inductive thinking; solving simple recurrences

III. Dynamic Programming (2-3 weeks)

Topics: string searching (Knuth-Morris-Pratt), All-Pairs-Shortest-Paths (Floyd-Warshall)

Projects: sequence alignment via dynamic programming; solving weakly-NP complete problems with "small" integers (e.g. knapsack); "seam-carving"

IV. Linear Programming, Network Flow, and NP-completeness (2-3 weeks)

Topics: formulating a variety of problems as an LP; simplex algorithm; network flow (Edmonds-Karp); bipartite matching via network flow; Integer Programming is NP-hard (assert); simple reductions from IP to demonstrate NP-hardness of other problems

Projects: business logistics type example for LP; experiment with heuristics for Travelling Salesperson Problem

Skills: problem abstraction and transformation; identifying intractability

Bonus topic: a glimpse of approximation algorithms: factor 2 approximation to (metric) TSP using MST

Introduction to Numerical Algorithms

Prereqs: CS 1, Ma 2a

1. Numerical methods for ODE (2 weeks)

Euler, trapezoidal, Runge-Kutta

Truncation error and order of accuracy

Solution error and error control

Linear stability analysis

Stiffness

Explicit and implicit schemes

Application example: N-body problems, video games, JPL mission trajectories slingshot off Jupiter

2. Numerical linear algebra (2 weeks)

Ax = b

direct methods

algorithm complexity

iterative methods, convergence

Application example: Poisson problem (see FDM below), Google page rank algorithm

3. Numerical PDE (4 weeks)

finite difference methods for elliptic and parabolic problems

error analysis, convergence, stability

1D and 2D problems

Spectral methods

DFT and FFT

Application example: unsteady stream function/vorticity formulation, Karman vortex street

4. Numerical Optimization (2 weeks)

Unconstrained optimization

Optimality conditions, convexity

Newton's method, conjugate gradient

Local and global convergence analysis

Lagrange multipliers and the KKT optimality conditions

Application example: chemical equilibrium for arbitrary numbers of species interacting to form arbitrary products (e.g. DNA complexes)

Details of Physics

The primary goal of the physics core is to have all Caltech students understand the application of fundamental natural laws and rigorous mathematical inference in providing detailed quantitative understanding of a broad range of physical systems, from sub-atomic particles to the large-scale structure of the universe.

The current physics core as of 2010 consists of 5 terms of physics: Ph1abc, and Ph2ab or Ph12abc (Students taking Ph 12a but not Ph 12c must take one term in Statistical Physics or Thermodynamics from a list).

Ph 1 abc. Classical Mechanics and Electromagnetism covers (calculus-based) Newtonian mechanics and celestial mechanics, electricity and magnetism, and relativity. Ph1bc will continue to have "analytical" and "practical" tracks.

Ph 2ab Waves, Quantum Mechanics, and Statistical Physics covers vibrations, waves, and introductory quantum physics in the first term, and statistical mechanics and thermodynamics in the second term.

Ph 8 bc. Experiments in Electromagnetism will continue to be offered in the second and third terms as a supplement to Ph 1bc, as an Introductory Lab.

Ph 12 abc. Waves, Quantum Physics, and Statistical Mechanics covers vibrations and waves in the first term, introductory quantum physics in the second term, and statistical mechanics and thermodynamics in the third term. These three terms build upon each other and are not intended to be taken separately.

The proposed revision reduces the number of physics core courses to 4 terms, in order to make room for new core course requirements.

A student intending to major in physics, astrophysics, applied physics or related fields will take Ph1abc (freshman year) and Ph12abc (sophomore year), as before.

A student who chooses an unrelated major and who chooses to take a minimum of physics will take Ph1abc (freshman year) and one term of physics (sophomore year) drawn from a menu of self-contained one-term courses emphasizing modern physics.

These menu courses would replace the current Ph2 (they may be called Ph2abcd…). They will, in general, be less mathematical and more "applied" than Ph 12abc, and can be geared towards specific engineering or scientific disciplines.

Examples:

- Waves for engineers/CS/EE
- Statistical mechanics and thermodynamics from a physics perspective (current Ph2b).
- Quantum Mechanics for Engineers
- Quantum Mechanics for Biologists and Chemists
- The structure of matter: Atoms, molecules, crystalline solids
- Nuclear physics for Engineers

Details of Math

The Math component of the core will consist of 4 courses, arranged as follows:

1. Ma1a (9 units), offered during the Fall term of Freshman year in three “paths”
2. Ma1b (9 units), offered during the Winter Term Freshman year in two “paths”
3. Ma1c (9 units), offered during the Spring Term Freshman year in two “paths”
4. Math 2 Menu (9 units), offered during the sophomore year, when the students can choose between Ma2a (Differential Equations, in two paths) and Ma2b (Probability and Statistics), or another menu course dealing with math.

The incoming students can place out of one or more of the courses through a series of placement exams that they will receive during the summer before arriving on campus as freshmen. All entering students will be asked to take a Diagnostic test ascertaining proficiency in high school mathematics needed for taking the standard path at Caltech.

Ma1a. Introduction to the Mathematical method via one-variable Calculus

Object: Develop the central results of one-variable Calculus, explaining why they hold, and under which hypotheses, illustrated with examples; also delineate how to write logically correct arguments. The focus is on critical thinking and not busy work. This forms the basis of all the Math courses; AP Calculus-BC is no substitute.

PATHS

There will be **two main Paths** in Ma1a. Path 1 can only be taken by those students who pass the Diagnostic test, while Path 2 will be for those who either don’t pass the Diagnostic test (by either not taking it or not doing sufficiently well in it) or else just want to see the material covered at a slower pace with more examples. In addition, there will be three **auxiliary paths** for those who place out of Math 1a; see below.

Path 1. One-variable Calculus with Foundations (9 units; 2 lectures + 1 recitation section per week)

This path is currently envisioned for approximately 80% of incoming students.

Topics covered: (weekly)

1. How to write proofs from first principles, involving induction, real numbers, rational approximations
2. Sequences and series: absolute and conditional convergence, Power series, tests
3. Continuous functions: Existence of extrema on closed intervals, small span, examples
4. Derivatives: Mean Value theorem, critical points, max/min, curve sketching
5. Integral Calculus: Fundamental theorems, primitives (anti-derivatives), substitution
6. Integration by parts, logarithm and exponentials
7. Polynomial approximations, Taylor series
8. Indeterminacies, L’Hopital’s rule, Limits
9. Improper integrals, Stirling’s formula
10. Complex numbers and functions, e^{i\pi}=-1

Path 2. Freshman Mathematics (9 units; 3 lectures + 1 recitation section per week) This path is currently envisioned for about 10% of incoming students.

Intended for students who may not have a thorough background in Mathematics or else may desire a more relaxed treatment of One-variable Calculus.

The lectures will cover all the topics from Path 1 above except for those dealing with infinite series, but with more detailed explanations and examples. This will be a kinder, gentler form of Path 1.

Students who are in this path will be asked to take, in addition, **Ma1d (5 units)**, which will be taught in the Winter quarter for seven weeks, which will complete all the relevant topics, mainly infinite series, (from Path 1) needed to be able to take Ma 1c (Vector Calculus) later in the Spring quarter.

Auxiliary Paths. These are intended for students with stronger preparation in mathematics, as indicated by their placing out of Ma 1a (by passing the appropriate Placement Exam). About 10% of the incoming students may be in this category.

There are three possible auxiliary paths for such students:

1. They can take Ma2a (Differential Equations) during the Fall of their Freshman year.
2. If they manage to place out of Ma2a as well (which will mean that they place out of Ma1b,c in addition), they can get placed in a higher level Math course such as Ma 108 (Introduction to Mathematical Analysis). Or they can place into Ma 6 (Discrete Math) or Ma 5 (Algebra). Such students may also take ACM 95.
3. If the students place out of Ma 1a-c and Ma 2b without placing out of Ma 2a, they can take Ma 2a, Ma108 (if interested), or get placed into Ma6 or Ma 5.

Problem solving: The recitations will focus on problem solving and on understanding logical arguments.

The students who want more exposure to the former may audit (or take for credit) the following course, which is not part of the core but could be very helpful to some:

Ma8. Problem Solving in Calculus (3 units)

This is a support class for Ma 1a, taught in the Fall of the Freshman year and takes a hands-on approach. The students will learn in great detail how to look for the answer, find limits, write a precise argument, etc. The course will also illustrate concepts with interesting examples, such as the *Mandelbrot set* using complex numbers and the recursion of f(z)=z^2+c.

Ma1b. Linear Algebra

Object: Develop the central results of the subject, explaining why they hold, and under which hypotheses, illustrated with examples and logical arguments.

The main aim, besides introducing this important subject of independent interest, is to establish the basic results that will be needed in **Ma 1c** (*Vector Calculus*).

Topics covered: Matrices, linear transformations, bases and existence, inner products, orthonormalization, eigenvalues and eigenvectors, *when and how* of diagonalization, symmetric and hermitian matrices

PATHS

There will be **two main Paths** in Ma1b. Path 1, called the ***Analytical track*** is meant for students who are comfortable with abstraction, while Path 2, called the ***Practical track***, is for students who like a more hands-on approach via concrete examples. In addition, there will be two **auxiliary paths** for those who place out of Math 1b; see below.

Path 1. Linear Algebra- Analytical Track. (9 units; 2 lectures + 1 recitation section per week)

This path is envisioned for approximately 40% of Freshmen.

This track will treat the topics above with rigor and for general vector spaces, real and complex, and study general linear transformations, including orthogonal and unitary ones. The fundamental theorem of Algebra will be discussed, deducing from it the existence of eigenvalues. Non-trivial examples will be discussed. This track is meant for students who like Math, but not necessarily those who want to major in Math. Typically, this is taken by students in Physics, Math, and some from Engineering and Chemistry.

Path 2. Linear Algebra- Practical Track. (9 units; 2 lectures + 1 recitation section per week)

This path is envisioned for approximately 50% of Freshmen.

This track will treat the same basic topics, but with an emphasis on problems related to two and three-dimensional spaces. Matrices, and not abstract linear transformations, will be paramount, and concepts likes diagonalization will be discussed in a more concrete context (than in the Analytical track). There will be many examples. This track is typically taken by students in Biology, Geology, and some from Engineering and Chemistry.

Auxiliary Paths. These are intended for students with stronger preparation in mathematics, as indicated by their placing out of Ma 1a, 1b (by passing the appropriate Placement Exam). About 10% of the incoming students may be in this category.

There are two possible auxiliary paths for such students:

1. They can take Ma2b (Probability and Statistics) during the Winter term of their Freshman year.
2. If they manage to place out of Ma2b as well, they can get placed in a higher level Math course such as Ma 108b (Introduction to Mathematical Analysis), but this can only be done if they have either placed out of Ma2a or have taken Ma 2a in the Fall. Or else they can place into Ma 6b (Discrete Math - Combinatorics) or Ma 5b (Algebra). Such students may also take ACM 95.

Ma1c. Vector Calculus

Object: Develop the central results of the subject, explaining why they hold, and under which hypotheses, illustrated with examples and logical arguments.

The main aim, besides introducing this important subject of independent interest, is to establish some of the the basic results that will be needed in **Ma 2a** (*Differential Equations*) and in **Ma2b** (*Probability and Statistics*).

Topics covered: Functions of many variables, limits and continuity, Differentiation in higher dimensions, gradient, Vector fields, Max/Min, Hessian test, divergence, curl, Line integrals and path independence (of special vector fields), Parametrized surfaces in 3-space, change of variables, theorems of Stokes and Gauss.

PATHS

There will be **two main Paths** in Ma1b. Path 1, called the ***Analytical track*** is meant for students who are comfortable with abstraction, while Path 2, called the ***Practical track***, is for students who like a more hands-on approach via concrete examples. In addition, there will be two **auxiliary paths** for those who place out of Math 1b; see below.

Path 1. Vector Calculus- Analytical Track. (9 units; 2 lectures + 1 recitation section per week)

This path is envisioned for approximately 35% of Freshmen.

This track will treat the topics above with rigor and for n-dimensional spaces, and study differentiability questions, negligible sets and their effect on integration, Fubini’s theorem, Jordan’s theorem, criteria for a vector field being conservative, among others. Non-trivial examples will be discussed. This track is meant for students who like Math, but not necessarily those who want to major in Math. Typically, this is taken by students in Physics, Math, and some from Engineering and Chemistry.

Path 2. Vector Calculus - Practical Track. (9 units; 2 lectures + 1 recitation section per week)

This path is envisioned for approximately 55% of Freshmen.

This track will treat the same basic topics, but with an emphasis on problems related to differentiation and integration in two and three dimensional spaces. Concepts will be discussed in a more concrete context (than in the Analytical track). There will be many examples. This track is typically taken by students in Biology, Geology, and some from Engineering and Chemistry.

Auxiliary Paths. These are intended for students with stronger preparation in mathematics, as indicated by their placing out of Ma 1a-c (by passing the appropriate Placement Exam). About 10% of the incoming students may be in this category.

There are two possible auxiliary paths for such students:

1. If they manage to place out of Ma2ba as well, they can get placed in a higher level Math course such as Ma 108c (Introduction to Mathematical Analysis). Such students may also take ACM 95.
2. They can place into Ma 6c (Discrete Math – Set theory) or Ma 5c (Algebra). Or else they can take Ma 3 (Number theory) or Ma 4 (Chaos theory).

Ma 2 Menu

The students will have an option of choosing to take **one of the following** two courses for 9 units:

Option 1:

Ma2a. Differential Equations (9 units; 2 lectures + 1 recitation section per week)

This course will be offered in the Fall term.

PATHS

There will be **two main Paths** in Ma 2a. Path 1, called the ***Analytical track*** is meant for students who are comfortable with abstraction, while Path 2, called the ***Practical track***, is for students who like a more hands-on approach via concrete examples. In addition, there will be **auxiliary paths** for those who place out of Ma2, by taking higher-level Math classes.

Path 1. Differential Equations- Analytical Track*.*

This path is envisioned for approximately 35% of students.

This track will treat the topics above with rigor and for n-dimensional spaces, and study differentiability questions, negligible sets and their effect on integration, Fubini's theorem, Jordan's theorem, criteria for a vector field being conservative, among others. Non-trivial examples will be discussed. This track is meant for students who like Math, but not necessarily those who want to major in Math. Typically, this is taken by students in Physics, Math, and some from Engineering and Chemistry.

Path 2. Differential Equations- Practical Track.

This path is envisioned for approximately 55% of Freshmen.

This track will treat the same basic topics, but with an emphasis on problems related to differentiation and integration in two and three-dimensional spaces. Concepts will be discussed in a more concrete context (than in the Analytical track). There will be many examples. This track is typically taken by students in Biology, Geology, and some from Engineering and Chemistry.

Option 2:

Ma2b. Probability and Statistics (9 units; 2 lectures + 1 recitation section per week)

This course will be offered in the Winter Quarter. It will introduce the rudiments of the subject, spending roughly half the quarter on Probability and half on Statistics. The latter part will use some results from Vector Calculus, developed in Ma 1c. The approach for this course will be hands-on with many examples.

Option 3:

Substitute (with permission) an acceptable math alternative from a menu.

Details of Chemistry

The chemistry component of the core will consist of 3 courses,

1. Ch1a (6 units), offered Fall term in three "paths"
2. Ch1b (9 units), offered Winter Term in two "menu" courses
3. Ch3 (6 units), a suite of laboratory courses offered all three terms

Ch1a. General Chemistry

Central Questions:

What is the nature of the chemical bond in molecules, liquids and solids?
What gives rise to the trends observed in the Periodic Table?
What determines the properties of molecules and materials?

Quantum behavior of electrons and atomic structure

To address these questions, one must first understand the behavior of electrons, which are inherently quantum-mechanical. The course therefore begins by explaining the key results of quantum theory, including wave-particle duality, Heisenberg uncertainty principle, wave functions, quantized states of the hydrogen atom, absorption and emission of light, and multi-electron atoms.

Chemical Bonds

The various models for chemical bonding are presented, from Lewis dots to VSEPR to molecular orbital theory. Examples including simple diatomic molecules, coordination compounds and solids are given.

PATHS

There will be three Paths in Ch1a. All students attend **the same two base lectures** in Ch1a each week.

Path 1. General Chemistry (6 units; AP required. 2 lectures + 1 recitation section per week)

This path is envisioned for approximately 80% students.

Path 2. Basic General Chemistry (9 units; 3 lectures + 1 recitation section per week, limited enrollment approx 20 students)

This course is intended for students who have not had A.P. Chemistry or who may require a more in depth treatment of the material in Ch1. In addition to the same 2 base lectures, students will attend a third lecture, which supplements the base lectures by providing additional examples or fuller explanations.

Path 3. Advanced General Chemistry (9 units; 3 lectures + 1 recitation section per week, limited enrollment approx. 20 students).

This course is intended for students with stronger preparation in physics and mathematics, who could benefit from a more quantitative treatment. In addition to the same 2 base lectures, students will attend a third lecture.

Placement into Ch21ab or Ch41ab. Students (approximately 5% of class) who pass the placement exam will be allowed to take the organic chemistry or physical chemistry courses to meet their freshman chemistry core requirement.

Ch1b. (9 units)

Topics

This course covers the fundamental concepts in physical chemistry necessary for a quantitative understanding molecules and their reactions, as well as the closely related physical methods:

Spectroscopy (Vibration, rotations, electronic, NMR) and Mass Spectrometry
Thermodynamics and Statistical Mechanics
Kinetics and Reaction Rates

In addition, core areas in chemistry are presented, including

Properties of gases, liquids and solids
Ionic equilibria and electrochemistry
Organic chemistry
Chemistry of life

MENUS

Two independent menu classes will be offered. The syllabus of both menu courses would cover all the material, but with different weighting and perspective.

Ch1b. Menu 1. Physical/Materials

A more mathematical treatment of the fundamental physical chemistry. Emphasis on applications in Materials, Astrochemistry, Nanochemistry, Spectroscopy.

Ch1b. Menu 2. Organic/Biochemistry

This course will also cover the essential concepts in chemistry but will focus on developing a deeper understanding of organic chemistry and biochemistry

Ch3a/Ch3x/Ch3y (6 units)

Ch3a. Synthesis and Characterization of Coordination Compounds

Ch3x. Solar Energy

Ch3y. Introduction to Laboratory Biochemistry

Laboratory courses will be designed to complement the lecture courses through introduction to experimental and analytical methods, demonstration of key concepts (bonding, kinetics, thermodynamics, spectroscopy) and the synthesis and characterization of compounds.

IV. NET TEACHING LOAD:

Ch1a. 3 Professorial faculty

Ch1b. 2 Professorial faculty

Ch3. Instructional staff, professorial oversight and development of new laboratories

Results of Faculty Poll

Core reform cannot be simply a slight shuffling of requirements; achieving the philosophical goals of a reformed core requires significantly more changes than numbers of courses. However, specific course requirements are still the bedrock on which the core rests. Thus, we sought to understand the range of faculty opinions on which topics should be taught in the core. In our survey we asked detailed questions about topics, but also the simple question of how many classes should be required in each subject. We found the results enlightening. The following table shows the *maximum* number of units of each subject recommended by the majority of the faculty.

	Physics	Chemistry	Math	Biology	Engineering	Inter-disciplinary
All faculty	4	3	5	2	1	1

The difference between this majority opinion and the current core is a simple reduction of one term of physics and addition of one term of biology and engineering.

Breaking down the responses into different faculty options shows interesting patterns. In the following table we highlight the major differences between "all faculty" and faculty in a few broadly defined areas. In particular we find that the majority of chemists recommend less math and less physics, while the majority of biologists recommend less chemistry. No strong consensus emerges on "engineering" and "inter-disciplinary."

	Physics	Chemistry	Math	Biology	Engineering	Inter-disciplinary
All faculty	4	3	5	2	1	1
Only Phys	4	3	5	2	1	2
Only Bio	4	2	5	2	1	2
Only Chem.	3	3	3	2	2	2

Only Eng	4	3	5	2	2	1
Only GPS	4	3	6	1	1	2

Finally, we view the result not by only included specific faculty, but instead of excluding specific faculty. In particular, we are interested, for example, in how much biology everyone *except* the biologists recommends. The results here are also instructive.

	Physics	**Chemistry**	**Math**	**Biology**	**Engineering**	**Inter-disciplinary**
All faculty	4	3	5	2	1	1
No Phys	4	3	5	2	1	1
No Chem	4	3	5	2	1	1
No Bio	4	3	5	2	1	1
No Math	4	3	4	2	1	1

The majority of faculty in areas in which physics would not be a requirement recommends 4 or fewer terms of physics. Faculty in areas in which chemistry would not be a requirement recommend 3 terms of chemistry. Faculty in areas in which biology would not be a requirement recommend 2 terms of biology. Faculty in areas in which additional math would not be a requirement recommend 4 terms of math. The only difference between the results from all faculty and from these subsets is in the math requirements, where faculty in areas without richer math requirements believe one term less math is appropriate.

The committee did not consider this survey a vote to be blindly followed, but it still views these results as a valuable statement of the general attitudes of the faculty. We also considered that, in most cases, many of the current core requirements would likely be instituted as option requirements, given their broad support.