2012 Revisions to the Core Curriculum

Council on Undergraduate Education

June 5, 2012

Introduction:

This document outlines the changes to the core for students entering in fall 2013, as well as the changes that occurred in 2011. To provide a context for these changes, this document also provides a short history of evolution of the core over the past 25 years and a description of the processes that motivated the current proposal. The changes below have been approved by the Core Curriculum Steering Committee (CCSC), Curriculum Committee (CC) and the Faculty Board (FB), except where noted.

Changes for students entering in fall 2013:

1. Reduce the requirement in mathematics to 27 units from the current 45 units. All students would be required to take Ma 1abc (Calculus of One and Several Variables and Linear Algebra). The current Ma 2ab would be divided into two courses: Ma 2 (Differential Equations) and Ma 3 (Probability and Statistics). These courses would have Ma 1 as a prerequisite; Ma 2 would not be required for Ma 3. (The changes to Ma 2 and 3 have not gone to the CC or the FB).
2. Reduce the requirement in physics to 27 units from the current 45 units. All students would be required to take Ph 1abc (Classical Mechanics and Electromagnetism). The current two-term Ph 2 would be expanded to a three-term sequence Ph2abc (Ph2a Waves and Vibrations; Ph2b Quantum Mechanics; Ph 2c Statistical Physics). A preliminary description of the revised Ph 2 is given in the Appendix B. (The changes to Ph 2 have not gone to the CC or the FB).
3. Students will continue to be required to take a total of 12 HSS courses, which includes two introductory and two advanced humanities courses, two introductory and two advanced social science courses, plus four additional HSS courses of the student's choosing. There would be an additional requirement that a student must complete on grades three writing-intensive HSS courses; these courses should be spread out over the student's sophomore, junior, and senior years. The writing-intensive HSS courses include the advanced humanities courses (humanities courses numbered over 100 but not including the foreign language courses) and a selection of social science courses. The social science faculty is reviewing the courses that will count towards the advanced social science requirement as well as the introductory courses. For fall 2012, they voted to remove BEM 101 Accounting from the list of courses that count towards the 4 additional HSS courses. More details about the changes within the HSS course to increase writing proficiency can be found in Appendix C.
4. All students must take *on grades* a minimum of 3 units in science or technical writing.

5. Students entering Caltech with exceptional backgrounds in mathematics, physics, chemistry, or biology will be given the opportunity to take placement exams (typically equivalent to a Caltech final exam) in these fields to fulfill a portion of the core requirements (such as Ma 1abc, Ph 1abc, Ch 1ab, or Bi 1). If a student passes an exam, the student will be awarded credit for one term of work. Currently, this policy is used in physics and mathematics, but not in chemistry or biology.

With these changes, the core curriculum would drop from the current 255 units to a total of 219 units. A listing of the core requirements (including those proposed above) for students entering in fall 2012 is listed below.

Core Curriculum for Fall 2013	
Mathematics (Ma 1abc)	27
Physics (Ph 1 abc)	27
Chemistry (Ch 1 ab)	15
Biology (Bi 1, 1x, 8, or 9)	9
Menu Course	9
Chemistry lab (Ch 3a, 3x)	6
Additional laboratory	6
Science writing[1]	3
Humanities (2 intro and 2 advanced)[2]	36
Social Science (2 intro and 2 advanced)[3]	36
Additional HSS[4]	36
Physical education (3 courses)	9
Total	219

[1]Although all options have an oral communication requirement, it is not officially part of the core curriculum.

[2]The advanced humanities courses include those numbered over 90 in art history, English, film, history, history and philosophy of science, humanities, music, and philosophy. These courses must be taken on grades.

[3]The advanced social science courses are currently under review by the social science faculty.

[4]BEM 101 Accounting (for fall 2012, this course will be renumbered BEM 102) will not count towards these additional courses.

It is expected that some options will continue to require some or all of the material found in the current Ma 2ab, and Ph 2ab. Hence, these courses may become option requirements rather than core requirements. However with the revised core, some options will have more flexibility in determining appropriate math and physics curriculum for their students (including the timing of when these courses will be taken by students within the option); options may also choose to add new requirements in science, mathematics, computing, or engineering, or to develop other courses suitable for their students. Table 1 lists the options along with the required number of units, an indication of the number of units required outside the option (such as computer programming, mathematics, or other science and engineering courses) and whether the option allows for a senior thesis or an engineering project for graduation.

Changes for students who entered in fall 2011:

Several changes to the core curriculum were approved by the FB in spring 2011 for students entering in fall 2011, as listed below.

1. For the first two terms of freshman year students are limited to 45 units of academic courses. Freshmen may take up to 51 units with the 6 remaining units to be used for frontier ("pizza") courses, PE, PA, or research.
2. Shadow grades are given during fall term freshman year (previously shadow grades were given just in winter term).
3. The two courses used to fulfill the advanced humanities requirement are taken on grades; foreign languages do not count towards the advanced humanities requirement.
4. The two courses used to fulfill the advanced social science requirement are taken on grades.
5. An elective freshman seminar program was initiated.
6. In addition to these recommended changes, for fall 2010 the faculty members in mathematics revised the content of Ma 1a; the faculty and the undergraduate Dean have also introduced a new program (Math 0) to support student learning; these changes and a description of the math courses are described in more detail in Appendix A of this report.

Background:

The Caltech faculty has periodically established committees to review the core curriculum. These committees have offered similar motivations for proposing change: recognition of the need for academic flexibility and the increasing diversity of scientific fields and interests of the student body. However, these committees have also noted the importance of academic rigor and breadth across the sciences.

In 1986 the Ad Hoc Committee on the Core Curriculum noted in their recommendations that the "'liberal science education' as embodied in the Caltech core curriculum is fundamentally sound and offers the best preparation for bright and creative young men and women in science and engineering." However, they also noted, "As it presently stands, it is too intense and stifles intellectual curiosity." To improve the situation they recommended a reduction in the core from 264 to 255 by dropping the 6-unit computing requirement and reducing the 9-unit additional laboratory requirement to 6 units. The committee also recommended an overall reduction in the total number of units for a bachelor's degree from 516 to 480. The committee suggested that the work load in some of the core courses be scaled down, the number of core courses taken by freshmen be reduced from 5 to 4, and stressed that freshmen and sophomores be discouraged from overloading. Some of these changes were implemented in the 1988-89 academic year; the core units were reduced to 255 through the suggested reductions and the total required units was cut to 486 (with the exception of the Math and Applied Math program, which required 483 units).

From 1993 to 1996, the core curriculum was again a topic of discussion in Faculty Board. In spring of 1995, the faculty voted on a recommendation to restructure the core curriculum to reduce the number of units required in mathematics, physics, and chemistry by 9 units, 9 units, and 3 units, respectively, and to add two science menu courses for 18 units and scientific communication for 3 units. In addition, the faculty voted to recommend the establishment of the Core Curriculum Council. In early 1996, the newly-formed Core Curriculum Steering Committee (CCSC) of the Core Curriculum Council wrote, "Core curriculum reform at Caltech recognizes the strength and value of the existing core yet seeks to incorporate some aspects of science that are currently missing but so important in the modern scientific world and society." This committee recommended changes to content of the required physics, mathematics, and chemistry courses to accommodate the reduction in units. In addition, the CCSC also recommended that one of the science menu courses be a topic-oriented course in biology and the second be chosen from a short list of courses including Ay 1 (Astronomy) and Ge 1 (Earth and the Environment). The changes to the science and mathematics courses were introduced for students entering in the fall of 1996; the 3-unit science writing course (Core 1ab) was introduced as a junior-level course in the 1999-2000 academic year.

Since 1996, a number of changes to the core have occurred through the actions of the CCSC. The biology requirement can be met by a student taking either Bi 1 (Principles of Biology), Bi 1x (The Great Ideas of Biology: An Introduction through Experimentation), Bi 8 (Molecular Biology), or Bi 9 (Cell Biology). Students also have a choice of the required chemistry laboratory:

Ch 3a (Fundamentals of Experimental Chemistry) or Ch 3x (Experimental Methods in Solar Energy Conversion). There are typically four or five menu courses offered in a given year, including Ay 1, Ge 1, ESE 1 (Introduction to Environmental Science and Engineering), and IST 4 (Information and Logic); next year there are plans to also offer EST 2 (Energy and Society). The Core 1 course has been replaced by a half-dozen different courses that are offered through the options; students may also elect to take a 9-unit science writing course (En 84). The practical track of Ph 1bc no longer contains a take-home laboratory component; instead students may elect to take the Ph 8bc (Experiments in Electromagnetism) to fulfill their introductory lab requirement.

Current Status and Review:

The proposed changes to the core are a result of considerable discussion over the past five years by faculty and students through several ad hoc and Faculty Board committees. The motivations for the changes follow the pattern of offering students an increase in flexibility and choice and acknowledging the ongoing changes in academic fields and student interest.

To understand the changes in the interests of the student body, Table 2 presents the percentage of graduates across the B.S. options from 5, 15, and 25 years ago (as three-year averages) as well as the current distribution of our sophomores, juniors, and seniors (based on the student's first option). In addition, the table shows the percentages of graduates from U.S. universities in the science and engineering fields represented at Caltech. At Caltech, there has been an increase in the percentage of students studying biology, which is mirrored in the national data; however, our percentage is significantly lower than the national percentage (10-13% compared to 35%). Enrollment in chemistry has been flat, while chemical engineering shows a recent increase. Caltech has seen a decrease by approximately 50% in the percentage of students studying electrical engineering, which is also consistent with national trends. The drop in the percentage of students obtaining degrees in EAS is offset by the introduction of degree programs in mechanical engineering and computer science – currently the two most popular options at Caltech. (Note that the EAS degree requirements were tightened in 2004 so that students had to complete one of the suggested concentrations or design a curriculum that is pre-approved by the faculty; the mechanical engineering and computer science B.S. programs were introduced in 2002 and 2003, respectively.) The degrees offered through the GPS division have remained around 2-3% of the total. In PMA, the percentage of students studying astronomy (now called astrophysics) and mathematics has been stable; the percentage of students studying physics has declined but the percentage is still significantly higher than found across U.S. universities.

Table 3 presents data on the distribution of academic interests of students who applied to Caltech, were accepted, and matriculated in fall 2011. Compared with national numbers, we have a significantly lower fraction of students applying and enrolling who are interested in biology and computer science than found on the national front, and a significantly higher fraction interested in physics and mathematics.

Returning to the recent discussions on the core curriculum, President Chameau appointed in 2007 an ad hoc committee to look at issues surrounding the academic and social lives of the undergraduate and graduate students. One recommendation from this committee involved the core curriculum. The committee recommended, "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." The full report can be found with the Faculty Board minutes of October 15, 2007 (minutes from the Faculty Board and Faculty Meetings can be found on the Officers of the Faculty website https://oof.caltech.edu/). At this meeting, the Faculty Board also voted to establish an ad hoc committee to review the core. At a Faculty Meeting on November 19, 2007, the charge to the ad hoc committee was discussed and approved. The Core Curriculum Task Force (CCTF) was established in 2008.

Also in 2008, the President Chameau and Provost Stolper appointed an Aims and Needs Committee (ANC) with a broad charge to look at issues important to Caltech over the next five to ten years. One of their recommendations involved undergraduate education. As found in the minutes of the December 8, 2008 Faculty Board Meeting, the committee concluded:

> Maintaining an innovative and inspiring approach to undergraduate education is critical to attracting the best students, meeting the needs of a changing student population in a changing world, feeding our students' passion for science and engineering, and producing leaders who will have the greatest possible impact on society. Caltech already does a good job with respect to these goals, but the ANC recommends several additional measures:
>
> - Consistently promote high quality teaching of undergraduates across all divisions.
> - Create opportunities for freshmen and sophomores to integrate research into the academic year.
> - Move back to a system of face-to-face advising.
> - Widen the types of support available for extraordinary innovation in undergraduate education.
> - Encourage and promote breadth in course offerings on our campus and through complementary offerings from one or two strategically chosen partner institutions via electronically shared classes.
>
> In addition, the committee urges that we explore new ways to teach the core, such that the core material is better integrated, student-faculty interaction is increased, and research is incorporated into the freshman year.

After its establishment in 2008, the CCTF hosted several open discussions for students and faculty, including updates to the Faculty Board on November 9, 2009 and May 10, 2010, and a final report on December 6, 2010. In addition, the CCTF participated in the Caltech's accreditation review through the Western Association of Schools and Colleges (WASC reports can be found at http://www.accreditation.caltech.edu/)

In the final presentation, the CCTF identified 7 key components of the core curriculum reform, which were endorsed by the Faculty Board:

1. Renormalization of requirements across the key sciences;
2. Choices throughout the core;
3. An intensive emphasis on critical writing skills;
4. Early exposure to more faculty in non-lecture settings;
5. Exposure to new intellectual frontiers;
6. A commitment to innovative courses and excellent teaching;
7. A commitment to improved labs involving data collection & analysis and design & build.

Along with the key elements, the CCTF proposed a new core that reduced the mathematics and physics requirements to four terms each (with some flexibility among the required courses) and added a freshman seminar course, a course in programming, a course in computational algorithms, changed the additional laboratory course to a design and build laboratory, and increased the units associated with science writing and oral communication. They also suggested that the freshman humanities courses be on grades, as well as a total of 4 writing-intensive HSS courses; the HSS requirements would be reduced to 11 courses. In all, this recommendation would have increased the total units within the core by a total of 3 units. In addition, the CCTF noted that some committee members preferred a smaller alternative core involving 3 terms each of physics and mathematics, 11 terms of HSS, and the addition of a freshman seminar.

At the December 2010 meeting, the Faculty Board voted to request that the Council on Undergraduate Education (CUE), working closely with the Core Curriculum Steering committee, undertake a proposal for the implementation of a reformed core curriculum. To that end, the CUE organized a process to solicit feedback from the options on the proposed changes to the core. This information was presented and discussed at a Faculty meeting (April 26, 2011) and to the Faculty Board (May 9, 2011). At that meeting, the Faculty Board voted to endorse direction that CUE had proposed of a smaller core curriculum including 3 terms of physics and 3 terms of mathematics.

At the Faculty meeting on November 28, 2011, the executive officers of mathematics, physics, humanities, and social sciences presented their suggestions for the core requirements in their fields. This feedback, along with the discussions through the CUE, CCSC, and option representatives has produced the current recommendations.

Of the 7 key components from the CCTF report, the current recommendations address the first 3 items. The other areas deserve on-going attention and there are some current efforts. The freshman seminars do promote interactions between the faculty and the incoming undergraduates and expose students to new intellectual frontiers; the Curriculum Committee is working to promote more seminar offerings in the future. Also for the past few years, there has been an increase in the number of “frontier courses” offered to undergraduates. In 2011-12, 10

frontier courses were available to freshmen in ACM, Bi, BE, Ch, ChE, CS, EAS, EE, GPS, and Ph. The Provost's office is continuing to look at mechanisms to increase the quality of teaching on campus, including the establishment of a teaching and learning center. The Innovation in Education Fund (started in 2008) is a source of support for faculty interested in improving laboratory courses. The CUE should continue to review the recommendations of the CCTF as well as other issues raised, such as the adequacy of the science writing and oral communication courses, the possibility for students to do academic year research, and the quality of the laboratory courses.

Table 1. Option Requirements								
Division	**Option**	**Option units**	**Free units**	**Require computing?**	**Math or applied math outside of option?**	**Other science and engng outside of option?**	**Lab courses?**	**Thesis or engineering project?**
BIO	Biology	151 - 166	65 - 80	N	N	Ch 41abc	Y	Optional thesis
CCE	Chemical Engng	272 - 302	(-71) - (-41)	N	ACM 95abc	Ch 21ab, Ch 41abc	Y	Required project or thesis
	Chemistry	151 - 171	60 - 80	N	N	N	Y	Optional thesis
EAS	Applied & Comput-ational Math	174	57	N	27 units in Ma	27 units not in ACM or Ma	N	N
	Applied Physics	174 - 192	39 - 57	N	ACM 95abc	N	Y	Optional thesis
	Bio-engineering	223	8	Y	ACM 95 abc	57 units of Bi & Ch	Y	Optional project
	Computer Science	195	36	Y	Ma/CS 6a or Ma 121; 36 units of Ma, ACM or CS	18 units of EAS or Ma	Y	Required project or thesis
	Electrial Engng	217	14	N	ACM 95ab; ACM/EE 116	N	Y	Required project or thesis
	EAS (CNS, ESE and MS tracks)	177 - 186	45 - 54	Y	ACM 95abc	Y	Y	Required project or thesis
	Mechanical Engng	190 - 199	32 - 41	Y	ACM 95abc	N	Y	Required project or thesis
GPS	Geology	180	51	N	ACM 95abc or Ch 41abc or Ch 21 abc; either Ge 108 or ACM/ESE 118		Y	Optional thesis
	Geobiology	189	42	N	N	Ch 41abc; Bi/Ch 110; Bi 8,9, 10, 117, 122 plus menu	Y	Optional thesis
	Geo-chemistry	174	57	N	ACM 95abc; or ACM/ESE 118 plus Ch 41abc or Ch 21abc	included in menu selections	Y	Optional thesis

	Geophysics	156	75	N	ACM 95abc	included in menu selections	Y	N
	Planetary Science	186	45	N	ACM 95abc	54 units from a group of science & engng courses	Y	N
HSS	Business Economics and Management	168	63	N	ACM/ESE 118 or Ec 122; ACM & Ma as part of menu	45 units of science, math, engng courses	N	N
	Economics	168	63	N	Ma 112a or ACM/ESE 118 followed by Ec 122; ACM part of menu	45 units of science, math, engineering	N	Optional thesis
	English	153	78	N	N	54 units of science math, or engineering	N	Required thesis
	History	156	75	N	N	54 units of science math, or engineering	N	Required thesis
	History and Philosophy of Science	150	81	N	N	45 science, math, engineering	N	Required thesis
	Philosophy	156	75	N	N	54 units of science math, or engineering	N	Required thesis
	Political Science	153	78	N	N	36 units of advanced SS, science, engineering, math	N	Required thesis
PMA	Astrophysics	212	19	N	N	27 units science or engineering of which 18 must be outside of PMA	Y	Optional thesis
	Mathematics	165	66	N	18 units of ACM can be used for requirements	N	N	Optional thesis
	Physics	198-201	30-33	N	ACM and Ma as part of menu	9 uits of science or engng outside of Ph, APh, Ma, ACM	Y	optional thesis

Table 2. Caltech B.S. graduates and B.S. graduates in the U.S. in fields comparable to Caltech

Caltech B.S. Graduates (1st option)					Graduates in S&E in U.S.			
Caltech Option or Division	1986-88	1996-98	2006-08	current enrollment	NSF Classification of Institutional Programs	1986-88	1996-98	2006-08
Bi	6.6%	13.5%	13.8%	9.8%	Biological Sciences	21.3%	35.9%	34.9%
BIO total	6.6%	13.5%	13.8%	9.8%		21.3%	35.9%	34.9%
Ch	5.0%	6.4%	7.7%	4.9%	Chemistry	5.4%	6.0%	5.1%
ChE	3.6%	5.3%	4.7%	10.7%	Chemical Engng	3.3%	3.8%	2.1%
CCE total	8.6%	11.8%	12.4%	15.7%		8.7%	9.8%	7.2%
AMa/ACM	0.4%	1.6%	3.5%	4.7%				
APh	6.1%	3.6%	3.1%	2.9%				
BE	0.0%	0.0%	0.0%	6.3%				
CS	0.0%	0.0%	8.8%	12.9%	Computer Sciences	21.3%	14.3%	19.5%
EE	21.9%	9.4%	9.0%	9.3%	Electrical Engng	14.4%	9.1%	6.0%
EAS	28.0%	38.3%	7.6%	2.2%	Engineering (civil, material science, other)	10.0%	10.9%	12.4%
ME	0.0%	0.0%	10.9%	12.8%	Mechanical & Aeronautical Engng	10.3%	8.5%	8.9%
EAS total	56.4%	52.9%	42.9%	51.1%		56.1%	42.8%	46.8%
GPS	2.0%	1.7%	3.5%	2.2%	Earth, Atmospheric Ocean Sciences	2.6%	2.4%	1.9%
GPS total	2.0%	1.7%	3.5%	2.2%		2.6%	2.4%	1.9%
Ay	1.3%	1.9%	1.9%	2.2%	Astronomy	0.1%	0.1%	0.2%
Ma	4.1%	4.2%	7.1%	6.3%	Mathematics	8.9%	7.0%	7.0%
Ph	20.1%	13.0%	15.0%	12.1%	Physics	2.3%	2.0%	2.2%
PMA total	25.5%	19.2%	24.0%	20.6%		11.3%	9.0%	9.3%
HSS total	0.5%	0.9%	3.2%	0.5%				
Independent Studies Program	0.4%	0.0%	0.2%	0.1%				
Number Graduates or Enrolled Students	557	637	622	728				

Data from National Science Foundation. *Science and Engineering Degrees: 1966-2008* .

Table 3. Intended majors for student applying to Caltech for fall 2011

Fields of Study for Caltech's Applicants and Matriculants for Fall 2011					
	Percent Applicants	Percent Admitted Students	Percent Matriculants	Yield (Matriculants /Admit)	Percent Matriculants /Applicants
Biology	8%	11%	10%	33%	5.9%
Total BIO	8%	11%	10%	33%	5.9%
Chemistry	4%	6%	6%	37%	7.0%
Chemical Engng	7%	7%	6%	31%	4.0%
Total CCE	11%	13%	12%	34%	5.1%
GPS	0%	0%	1%		
Total GPS	0%	0%	1%		
HSS	1%	1%	1%	37%	4.7%
Total HSS	1%	1%	1%	37%	4.7%
Computer Science	11%	8%	5%	23%	2.1%
Electrical Engng	9%	7%	6%	31%	3.1%
Other Engng	22%	21%	18%	31%	3.8%
Mechanical Engng	13%	8%	11%	51%	4.0%
Total EAS	55%	44%	40%	33%	3.4%
Ay	3%	3%	3%	37%	4.7%
Ma	7%	13%	15%	42%	10.0%
Ph	10%	13%	16%	45%	7.5%
Total PMA	20%	29%	34%	43%	8.0%
Undecided	5%	2%	2%	37%	1.9%
Overall	100%	100%	100%	37%	4.7%

Data from the Freshman Admissions Report to the June 6, 2011 Faculty Board by Prof. Kim Border.

Appendix A.1

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

(From Dinakar Ramakrishnan)

Goal: 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. Emphasize critical thinking.

This course forms the basis of all the Math courses; AP Calculus-BC is no substitute.

PATHS

There are **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 are **auxiliary paths** for those who place out of Math 1a.

Path 1. Calculus of One and Several Variables (9 units; 3 lectures + 1 recitation section per week)

This path is currently taken by approximately 80% of incoming students, but we foresee the numbers lessening in the succeeding years as the (unfortunate) stigma attached to the second, more leisurely **Path 2** (see below) is steadily overcome.

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 and MacLaurin series
8. Indeterminacies, L'Hopital's rule, Limits
9. Improper integrals, Stirling's formula
10. Complex numbers, sequences, differentiability, factoring

The key changes which have been made since the Fall of 2010:

1. During the first week of classes it is explained, with many types of examples, how one writes proofs in mathematics. (In addition, the prefrosh are encouraged to try Ma 0 online during the summer before starting here, thereby getting an introduction to the fundamentals.)
2. Some material used in the previous years (in Ma1a) on the abstract side has been reduced or eliminated, partly to be able to give more examples and partly for being able to spend the first week explaining the writing of proofs.

3. Lecture Notes are posted, which are used by many who may have difficulty reading the text; right now more than half the students seem to read the notes. The plan is to add figures and (more) examples to the notes next year.
4. Care is taken to make the class appealing to the general Caltech freshman, not mainly to those for whom mathematical thinking comes easily. At the same time, enrichment notes are posted online, which are not (at all) needed for the course, but which appeal to some 20% of the class wanting to learn more than what is discussed in class. This allows the Professor to relax and not rush in class (as it may have at times been done in the past) to try to do something sophisticated to keep the interests of the top tier.
5. During Fall 2010, the class lectures were videotaped, and viewing them gives the students a way to go over the material at leisure.
6. The homework problems are chosen to reflect the basic things the students must know, and which they can do by following the lectures. Every week, there is one problem which is slightly more difficult (than the others), but is provided with hints, and the students are in any case encouraged to collaborate with others. In the future, care will also be taken to ensure that the (midterm and final) exams reflect correctly what the students have learnt to do.
7. Care is exercised in choosing very good Teaching Assistants for the course, and the students are encouraged to go to recitations, even more than one if needed, to learn the subject matter regularly. They can go to any recitation they want (as invariably some TAs are better at explaining), but they need to turn in the homework assignments to the appropriate TA monitoring their section. The homework problems are graded uniformly, meaning each problem is graded by the same (two) TAs for the entire class, so there is no bias in favor of one section or another.
8. The TAs and the Professor teaching the course maintain weekly office hours, and detailed reviews are given before the midterm and the final exam. The students can also go to as many different office hours as they like.
9. Students are encouraged to sit in, or register for, the *problem solving class* Ma8, which can be a helpful supplement to the course. This is especially recommended for the students who do not excel in the diagnostic test given in August (before they arrive).

Path 2. Freshman Mathematics (12 units; 4 lectures + 1 recitation section per week)

This path is currently taken by about 10% of incoming students. As mentioned above, we expect this percentage to go up some over the next few years, as students come to realize that it is advantageous to learn things in math a bit slowly to gain a thorough understanding without pressure.

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

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

Care has been exercised to choose excellent instructors for this course. It was a resounding success during the Fall of 2011, when Dr. Andrei Jorza taught this path.

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't take Ma 108, but they can take Ma 2a (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.

Appendix A.2

Math 0

(From Rod Kiewiet with help from Barry Simon, Eva Graham, Margaret Chiu, Leslie Maxfield, Roberto Pelayo and Dinakar Ramakrishnan)

Making the Transition to Caltech Mathematics

The transition from high school to college presents problems for all students, but for some students it is particularly challenging. At Caltech, many newly admitted students lack the background in mathematics that is necessary to succeed in Ma 1a. Unfortunately, few of them are even aware that their background in mathematics is deficient. This is not their fault. The mathematics curriculum in high schools is less rigorous than it was even a few decades ago. In conversations with Caltech students who have struggled with freshman mathematics, most report that they were star math students in high school, which of course is a major reason why they were offered admission to Caltech in the first place. Many of them, however, have never seen mathematics as it is taught at Caltech.

Those who struggle in Ma 1a usually continue to struggle in the rest of the core mathematics classes. They earn relatively low GPA's during their first two years or so at Caltech, and when they graduate their GPA's are significantly lower than those of other students. And not all who struggle with freshman mathematics succeed; such students are also less likely than their counterparts to graduate from Caltech. The students often report that, in the end, they have also not learned very much math, as too much of the material was beyond their ability to comprehend at the time it was presented. Currently Caltech attempts to assist such students in a number of ways but this assistance may be too little, too late.

In order to understand the specific reasons why many of our freshman struggle in Ma 1a, the undergraduate Academics and Research Committee conducted an online survey that asked a series of specific questions about the difficulties they encountered in Ma1a. From the survey results, the most common area of weakness that students identified was that of formal reasoning, writing proofs, and common proof techniques. The results thus corroborate what most people connected with Ma 1a have known anecdotally—that many Caltech freshmen, though computationally skilled, struggle with basic proof concepts. Moreover, a corollary obstacle to students thriving in Ma1a is that, because it is a "calculus" course, students feel like they should be mastering the topic with ease. They are thus reluctant to go to classmates, TA's, or professors when they encounter difficulties.

Dean Kiewiet contacted Professor Roberto Pelayo, a Caltech Ph.D. in mathematics who is currently on the faculty of the University of Hawaii and who, for the past several years, has taught in the Caltech Freshman Summer Research Institute. The outline for an online course, Transition to Mathematical Proofs (TMP) that incoming freshmen could take at home this summer before their arrival at Caltech. The TMP course outline is as follows:

Structure of TMP

TMP provides an online resource for incoming Caltech freshmen that engages them in mathematical writing and in obtaining experience in constructing simple, but well-written and logically sound proofs. This online resource consists of approximately 10 modules, each consisting of a set of lecture notes, exercises, and a mechanism for submitting work. This submitted work is evaluated by teaching assistants and then electronically returned to the students.

Course Content

TMP focuses on strategizing and composing mathematical proofs using topics regularly found in Math 1a (e.g., continuity, differentiability, sequences) to demonstrate the various proof-writing techniques. In particular, TMP assists students in making the transition to a more analytic paradigm of calculus that focuses on proving theorems rather than performing computations.

Module Topics

- Formal Logic
- Set Theory
- Functions between Sets
- Cardinalities of Sets
- Subsets of the Real Line
- Continuity of Functions
- Differentiability of Functions
- Applying Continuity and Differentiability Theorems
- Sequences

Learning Outcomes

Incoming freshmen who successfully complete TMP will be able to:

- Write simple but logically correct proofs that utilize appropriate terminology and notation.
- Understand various proof methodologies, including direct proof, proof by contradiction, proof by contrapositive, and induction.
- Manipulate sets using the various set-theoretic operations and theorems.
- Compute the cardinality of various classes of sets.
- Prove when a function between sets is injective, surjective, and bijective.
- Prove or disprove that a real-valued function is continuous.
- Use the definition of the derivative to prove various differentiation properties.
- Use various differentiability and continuity theorems in proofs beyond calculus.
- Prove when a sequence converges or diverges.

Results:

The shadow grades in fall term were used to analyze the success of the Math 0 course in preparing students for Ma 1a.

Enrolled in Math 0? (includes Math1 Sect 1)				
Ma 1a shadow grade	No		Yes	
A	23	26.74%	64	51.61%
B	47	54.65%	51	41.13%
C	15	17.44%	9	7.26%
F	1	1.16%		
Total	86		124	

The average Math 1 GPA for persons not enrolled in Math 0 is 3.04. When a student enrolls in Math 0, the Math 1 GPA is 3.41—this difference is significant by statistical and practical standards.

Appendix B

(from David Politzer)

Physics Curriculum

Ph1a -- Mechanics: vectors, velocity, acceleration, uniform acceleration, F=ma, momentum, kinetic & potential energy, work, tension, pulleys, levers, springs, friction, fixed-axis rotations and angular momentum, Kepler orbits

Ph1b Practical – Electricity & Magnetism: Coulomb's law, electric field, Gauss' Law, potential (voltage), resistors, capacitors, diodes, DC and other possible circuits, electric energy, magnetic fields and forces and energy (prerequisite Ph 1a).

Ph1b Analytic -- Special relativity, vector calculus, electricity including Coulomb's law, electric field, Gauss' Law, potential, resistors, capacitors, DC circuits, electric energy (prerequisite Ph 1a)

Ph1c Practical – Electricity & Magnetism: magnetic materials, induction (Faraday's law), op-amps, AC circuits, filters, analog circuits, Maxwell's eq'ns & light, interference & diffraction, special relativity (prerequisite Ph 1ab)

Ph1c Analytic -- magnetic fields and forces, induction, AC circuits, Maxwell's eq'ns & light (prerequisite Ph 1ab)

Ph2a -- Vibrations & Waves: the oscillator (incl. damped and forced), coupled oscillators, normal modes, ideal string & wave eq'n, traveling waves, dispersion, Fourier series and analysis, pulses and wave packets, interference & diffraction (prerequisite Ph 1a)

Ph2b – Quantum Mechanics: experimental necessity (spectra, photoelectric effect, Bohr atom, deBroglie waves), Schroedinger eq'n, free particle, particle in a box, in a potential, harmonic oscillator, operators and commutators, variational method, tunneling, coherence & interference, periodic potentials, identical particles (prerequisite Ph 1a, Ph2a)

Ph2c -- Statistical Mechanics -- entropy, temperature, Boltzmann dist., chemical potential, Helmholtz & Gibbs free energy, ideal gas, Fermi & Bose gases, thermodynamics (prerequisite Ph 1a)

Appendix C

Writing in the Humanities
(From Cindy Weinstein)

During the 2010-11 academic year, the humanities faculty suggested two changes to the humanities requirements that were supported by the CCSC and the Faculty Board. To encourage students to take the humanities courses more seriously, students must now take at least two advanced humanities courses on grades. Secondly, foreign language classes no longer count towards the advanced humanities requirement (though they do count towards the four additional HSS requirements). This change was suggested by research indicating that many students were avoiding taking writing-intensive upper-level humanities courses altogether, instead satisfying their advanced humanities requirements with foreign language courses. This "language loophole" has now been closed.

For this academic year, the members of the humanities faculty have agreed to standardize the way in which writing is taught across the humanities. Alumni surveys indicate that students feel that Caltech did not give them proper training in writing. While the humanists are, of course, not solely responsible for teaching good writing practices, they recognize that they have a significant role, and have developed the following standards that all writing-intensive humanities courses must meet.

- At least 4000 words of writing must be assigned.
- Students must complete at least two formal essays, one due by midterm. At least one of these must be returned with feedback before drop day.
- Instructors must give substantial written feedback on papers. The written feedback must address matters of style, organization, and argument, as well as content. Feedback should be provided in a timely way, so that it is useful to students in later writing assignments.
- Instructors must clearly explain the expectations for writing assignments.
- In Freshman Humanities courses, at least one assignment must be focused on the writing process itself. For example, students might be required to revise a corrected paper, participate in an in-class peer reviewing exercise, or submit a thesis statement and outline in advance of writing their paper.

In addition, the humanities faculty would like to see a process whereby students have to do some writing each year, so that their skills do not deteriorate as they progress through Caltech. (It's been found that students write worse in their junior and senior years, presumably because they don't do enough of it.) Hence, the faculty have recommended that there is a total of three writing-intensive HSS courses be required, and that students take one of these courses in the sophomore, junior, and senior years.

For fall 2012 the humanities faculty are hiring a Writing Coordinator, who will teach courses in English and composition for incoming students who do not pass a diagnostic writing exam, provide support to the humanities and social science faculty as they implement more robust writing requirements, and establish a set of best practices that will enable students to master the challenges of written communication.