Report from the Graduate Qualifying Exam and Curriculum Committee
February 5, 2021

CONTENTS

1 SUMMARY

The committee worked with a complex set of opportunities, concerns, and constraints. This report outlines the recommendations that were adopted following a faculty vote, as well as the context surrounding them. Adopted recommendations are noted in blue. The committee's charge and membership are described in Section 2. Our methods of gathering input are described in Section 3. Comparisons, both with other graduate physics programs and with other graduate programs at Yale, are in Section 4. The committee recommendations begin with the Program Learning Objectives, outlined in Section 5. The Curriculum Recommendations are described in Section 6, beginning with the graduate school requirements, a description of the current curriculum structure, and a description of the changes adopted in 2018. The Qualifying Exam Recommendation is in Section 7, beginning with a description of the graduate school requirements and a description of the current qualifying exam. The Appendix contains more detailed information across many of these topics. This report includes suggestions for assessments of the impact of the recommendations as well as considerations for future curriculum or qualifying exam reviews.

Recommendations

For organizational purposes, the committee recommendations are listed here.

Learning Objective 1: Students will acquire a general foundational knowledge of physics at the graduate level and the necessary accompanying methodological aspects of mathematics, computing, and instrumentation.

Learning Objective 2: Students will learn to identify and solve problems at the frontier of physics knowledge, uphold standards of scientific integrity, and disseminate their research.

Learning Objective 3: Students will become educators and communicators with the ability to promote an understanding and appreciation of physics across the university and in society.

Learning Objective 4: Department members and students will work together to develop and realize, in the department and in the community, progress and success in diversity, equity, and inclusion in all aspects of the scientific enterprise.

Curriculum Recommendation 1: Return Mathematical Methods of Physics (PHYS 506a) to our list of required core courses and ensure that the links between the content of math methods and the applications in core courses are realized.

Curriculum Recommendation 2: The requirement on maintaining a high-pass average should be restricted to only consider the seven courses on which students performed best.

Curriculum Recommendation 3: Revise PHYS 515 to include a more comprehensive introduction to the various fields of physics research carried out in the department and to more formally introduce students to scientific reading, writing and presenting.

Curriculum Recommendation 4: Update PHYS 678, ”Computing for Scientific Research”, to include data analysis and modeling and offer this course on a regular basis.

Curriculum Recommendation 5: Develop and regularly offer a new elective on the topic of instrumentation.

Curriculum Recommendation 6: Restructure PHYS 990, ”Special Investigations” (SI), modeled after PHYS 470/471 with an overall course instructor who provides oversight and direction for the students enrolled.

Curriculum Recommendation 7: The Department should examine the course requirements for PEB students to look for potential overlap with Physics coursework with an eye toward possible reduction of Physics requirements for these students.

Qualifying Event Recommendation The committee recommends a fundamental shift in how the department fulfills the University's qualifying requirement from a ”pass/fail high stakes qualifying exam” to ”qualifying events”, which serve as a learning opportunity that students pass by nature of participating in the process. We recommend that the qualifying events be in support of learning objectives 1-3, crafted with the lens of learning objective 4. The recommended event builds on current experience in the department and occurs in two stages: (1) students will have an opportunity to review their foundational course content and (2) students will engage in a guided research experience and give a research presentation.

Foundational Course Content Component: The committee recommends a foundational knowledge qualifying event that all students take as a cohort at the beginning of their second year. The format of the event would borrow from the existing qualifying exam (range of topics, number of questions, level of problems, time allotted, etc.) The students' work would be marked, with gaps and errors indicated, and returned to the students. The students would then correct their mistakes over the course of the following week, with one-on-one access to senior graduate student mentors, and return their corrected problems to the qualifying committee, thereby completing this qualifying event.

Research Component: A presentation on the work undertaken in the revised PHYS 990 course (Curr. Rec. 6) will serve as the oral, research-based component of our department qualifying event, overseen by the PHYS 990 instructor. The student will introduce the field in which their research occurs, present their work, engage in a Q&A, and receive written feedback.

2 COMMITTEE CHARGE AND MEMBERSHIP

The committee was charged as follows:

The qualifying exam and graduate curriculum review committee is asked to undertake a fresh look at the graduate curriculum in the Physics Department and how we can best enable the success of current and future students. Specifically, the committee is charged with reviewing and formulating the learning goals of our graduate program and evaluating how course work, teaching, and research contribute to these goals. We ask the committee to critically evaluate what qualifying event would best serve these goals and whether different qualifying exams based on subfields should be considered. The committee is asked to pay special attention to and comment on how the structure of our program and choice of exam impact diversity, equity, and inclusion in our graduate program.

Given the unique situation due to COVID in AY 2020-2021 and considering the plans and boundary conditions for the spring semester we ask the committee to make a recommendation for the qualifying exam for this year as well as in the future.

The committee is expected to consult frequently with faculty and students.

The committee members are listed below:

- Professor Yoram Alhassid
- Hannah Bossi, 3rd year GS
- Assistant Professor Meng Cheng
- Associate Professor Sarah Demers, committee chair
- Professor Bonnie Fleming, Director of Graduate Studies
- Associate Professor Walter Goldberger
- Professor Karsten Heeger, Department Chair
- Associate Professor Daisuke Nagai
- Dr. Rona Ramos, Graduate Program Coordinator
- Sohan Vartak, 5th year GS
- Stacey Watts, Administrator

3 PROCESS

The committee met regularly in November and December of 2020 and January of 2021. We consulted with the faculty and graduate students, as described below, and also gathered information about requirements in other graduate programs in the sciences and mathematics at Yale and in physics departments at other institutions, as summarized in the following sections and in the appendix. The committee had wide-ranging discussions regarding the program objectives, curriculum and qualifying process, including the relationship between these subjects and diversity, equity and inclusion in the program and the current unique situation due to COVID, as charged.

The committee consulted with the faculty in a number of ways:

- We provided regular updates in faculty meetings
- We surveyed the faculty, receiving 23 responses
- We received email directly from faculty members
- We provided an online form for anonymous input
- We held one-on-one meetings with interested faculty members

The committee consulted with the graduate students in a number of ways:

- We surveyed the graduate students, receiving 51 responses
- We held a town hall for graduate students (December 4, 2020)
- We provided an online form for anonymous input
- We held one-on-one meetings with interested graduate students

4 PROGRAM COMPARISONS

While the Yale Physics Graduate Program determines its own structure, independent from choices made by other programs, it is nevertheless useful to understand how other graduate physics programs, and other physical science programs at Yale, structure their curriculum and qualification requirements. We therefore consulted with the program descriptions online and constructed comparison tables in the categories of course requirements (as of December, 2020) and qualification exam formats, as provided in the following sections.

4.1 Course requirements in other graduate programs in physics

A comparison of the curriculum requirements for twenty graduate programs in physics (programs ranked in a recent US News and World Report ranking[1]) is provided in Table 1. Note that apples-to-apples comparisons between programs are difficult due to varying program structures, levels of flexibility afforded to students, and content of courses that are similarly named. Additionally, several of the program descriptions were challenging to decipher. While care was taken constructing the table, it should be considered only as giving a loose range of choices that various programs are making and not a definitive description of the programs surveyed.

Several observations can be made:

- All twenty programs include electricity and magnetism, statistical mechanics, and quantum mechanics as components of their core curriculum, either requiring students to take courses on these subjects or to demonstrate their mastery via previous coursework or a written or oral exam.
- 75% of the programs consider classical mechanics part of their core curriculum, as defined above.
- Comparisons of the inclusion of mathematics across programs was a challenge. Some programs explicitly listed math methods courses in their departments, others pointed to courses in other departments, or noted undergraduate courses that they offer which students can take, or demonstrate mastery of, from previous course work. This column of the table should therefore be considered incomplete.
- Many programs have developed dedicated courses to introduce their students to research in their departments, and to teaching and/or communicating physics.
- There is a huge range in total number of required courses (not counting research for credit), with UCSD requiring twelve, and Maryland and UIUC only requiring two. The schools will low requirements note that many students take the suite of core courses and additional courses in their research disciplines. The Yale Physics Graduate Program is in the lower/middle range in terms of number of required courses.

4.2 Qualifying Exams in the Physical Sciences and Mathematics at Yale

All of the graduate programs at Yale are functioning within the same set of requirements outlined by the graduate school, including the qualifying exam and honors grade requirements. While there is no need for uniformity in the implementation of the qualifying exam, or in additional course and grade requirements across programs in different disciplines, it instructive to survey the structure of other programs. A summary of the qualifying exam implementation is provided in Table 2. It is clear that there is a range of approaches taken to the qualifying exam requirement across these programs, from written tests on foundational content (Applied Math, Mathematics) to research presentations (Applied Physics, Chemistry, Computer Science, Earth & Planetary Science) or both (Astronomy.) Additional details of these exams can be found in the Appendix.

4.3 Qualifying exams in other graduate programs in physics

The programs surveyed for the physics program curriculum comparison were also surveyed for their qualifying exam structure. A summary is provided in Table 3 and more complete information is provided in the Appendix (A.3).

Several observations can be made:

- 85% of the programs require an oral exam, though the content of this exam varies considerably. For example, Stanford requires students to be tested on foundational physics knowledge and an area of research outside of their discipline, Cornell requires a foundational-knowledge oral exam as well as a research-based oral exam, and many programs have oral exams designed around students' area of research interest either focused on general knowledge of the subject area or on a particular proposed thesis topic.
- 40% of the programs have written exams that assess students' foundational knowledge of physics, though here, again, there are many variations. For example, Princeton's exam provides the students with three questions on each of four topics from which they must choose two questions to answer, some programs test at the advanced undergraduate level and some at the graduate level.
- Two of the programs (MIT and Chicago) require students to either successfully take their core classes or to pass a written exam on the topics of these core classes, with MIT additionally having a research-based oral exam.

[1] https://www.usnews.com/best-graduate-schools/top-science-schools/physics-rankings

Institution	MM	CM	EM1	EM2	SM	QM1	QM2	Req Ele	other req classes/comments
MIT		*	*		*	*		4	2 "specialty" + 2 "breadth" electives
Stanford	*		x		x			2	"Research Activities at Stanford", "Teaching of Physics Seminar" + QM1/2/3 or QFT1/2/3 proficiency in 6 UG math courses
Cal Tech	-	-	-		-	-	-	6	
Harvard			x		x	x	x	4	"Teaching and Communicating Physics"
Princeton		-	-		-	-	-		"Communicating Physics" + 3 courses 1 from QM/QFT, CM/BIO/AMO, & GR/HEP
Berkeley		-	x		x	x	x	5	"Introduction to Graduate Research", "Teaching Training Seminar"
Cornell			*		*	*			students typically take 7-16 courses.
Chicago		*	*	*	*	*	*	6	"Advanced Exp. Physics" req'd 4 intermediate, 2 adv. electives
UIUC		-	-		-	-	-	2	2 "breadth" courses req'd, 24 courses req'd including research for credit
Columbia		-	x		x	x	x	3	
UCSB		x	x	x	x	x	x	3/5	+ QM3 req'd, exp(theory) students: 3(5) electives
Yale		x	x		x	x	x	1	"Topics in Modern Physics Research" "Responsible Conduct in Research"
Michigan		-	x	x	x	x	x	2	QFT1/2 can replace QM1/2 "Ethics in Research" and "Colloquia" mini-courses also req'd
CO-Boulder		x	x	x	x	x	x	4	
Maryland		-	-		-	-	-	2	"Foundations and Frontiers of Physics" two courses outside specialty req'd
Penn	x		x		x	x	x	4	
JHopkins			x		x	x	x		
UCLA		x	x	x	x	x	x	2	+weekly colloquium (req'd 1 quarter) + survey of modern research areas
UCSD	x	x	x	x	x	x	x	5	"Instruction in Physics Teaching" (not req'd)
UT-Austin		x	x	x	x	x	x		+"pizza seminar" research intro

Table 1. This table provides a comparison of course requirements for twenty highly-ranked physics graduate programs based on our interpretation of the information available online as of December, 2020. The column definitions are as follows: MM = mathematical methods, CM = classical mechanics, EM1 = first semester electromagnetism, EM2 = second semester electromagnetism, SM = statistical mechanics, QM1 = first semester quantum mechanics, QM2 = second semester quantum mechanics, "Req Ele" = required number of elective courses in addition to core classes, "other req classes" = any additional non-standard required classes. The mathematical methods column must be considered incomplete due to challenges capturing the ways that math education is incorporated into the various programs. The electives column does not include courses that consist of research for credit. The key is as follows: "**x**" = **required course**, "*" = **must either take course or written qualifying exam on subject**, "**-**" = **course not required, but subject is on written qualifying exam**.

Yale Program	Qualifying Event
Applied Math	Students must pass written exam on general Applied Math knowledge (in algebra, analysis, probability and statistics) by the end of their 2nd year
Applied Physics	An ”Area Examination” must be passed before admittance to candidacy. Part I is an open oral presentation of the student’s research and plans, Part II is a closed Q&A, oral or written.
Astronomy	A written exam at the end of the 4th term tests field of astronomy and related math and physics is followed by an oral exam based on chosen field of research.
Chemistry	The candidacy examination consists of a written research proposal and two-hour oral presentation (45 min of prepared material, extensive Q&A on topic and related chemistry.)
Computer Science	In 2nd year students take a research course and write a report of their results. They must pass an ”area exam”, demonstrating broad knowledge of research in the area of their project.
Earth & Planetary Science	Students carry out two research projects (major and minor), write a research proposal for each, and give a 45 min. presentation followed by Q&A.
Mathematics	Students take 3 four-hour exams (on Algebra, Analysis, and Algebraic Topology). There is no limit on the number of times students can take the exams.

Table 2. A comparison of the implementation of the required ”Qualifying Event” across several programs in mathematics and the physical sciences at Yale. Additional details are available in the appendix.

Institution	Written	Written or courses	Oral
MIT		X	X
Stanford			X
Cal Tech	X		X
Harvard			X
Princeton	X		X
Berkeley	X		X
Cornell			X
Chicago		X	
UIUC	X		X
Columbia*	-		X
Santa Barbara			X
Yale	X		
Michigan	X		X
CO-Boulder			X
Maryland	X		
Penn			X
Johns Hopkins			X
UCLA	X		X
UCSD			X
UT-Austin			X

Table 3. A comparison of qualifying exam formats across twenty highly-ranked physics graduate programs constructed from information available online in December, 2020. The ”written” exams are typically focused on an assessment of foundational physics knowledge while the ”oral” exams are typically research-focused, though there are exceptions. Detailed descriptions of the exams are available in the Appendix (A.3). *Note that Columbia has, in the past, had a written component to their qualifying exam, which is currently suspended.

5 GRADUATE PROGRAM LEARNING OBJECTIVES

The Committee was charged with ”reviewing and formulating the learning goals of our graduate program and evaluating how course work, teaching, and research contribute to these goals.” In this section we provide the learning goals formulated in 2018, and the learning goals formulated by this committee, which build on the goals established in 2018.

We found in the course of our work that it was useful for us to expand the learning objectives beyond the level of detail provided below. When we presented these additional layers of detail to the students and faculty we received a significant amount of thoughtful feedback. It became clear to us that more time would be needed to fully develop more detailed objectives than what we provide below, and we have included our initial thoughts in this direction, along with a summary of feedback from students and faculty, in the Appendix (A.1) in case the department wishes to pursue this in the future.

5.1 Learning Objectives (2018)

The Learning Objectives formulated by the previous committee (in 2018) are as follows:

1. Give students general foundation of physics knowledge at the graduate level
2. Train students to become researchers and educators
3. Train students to identify and solve problems at the frontier of physics knowledge

These objectives, which we agreed with, served as our starting point. We felt that more detail would be needed to guide our committee in formulating recommendations, so we developed the learning objectives listed below.

5.2 Recommended Learning Objectives

The committee proposes the following learning objectives:

1. Students will acquire a general foundational knowledge of physics at the graduate level and the necessary accompanying methodological aspects of mathematics, computing, and instrumentation.
2. Students will learn to identify and solve problems at the frontier of physics knowledge, uphold standards of scientific integrity, and disseminate their research.
3. Students will become educators and communicators with the ability to promote an understanding and appreciation of physics across the university and in society.
4. Department members and students will work together to develop and realize, in the department and in the community, progress and success in diversity, equity, and inclusion in all aspects of the scientific enterprise.

The first program objective, regarding foundational knowledge, is largely addressed via our formal curriculum, which includes core foundational courses, special research courses, and a suite of electives. The committee makes several recommendations to ensure that our curriculum allows us to meet this objective. Assessment of this objective, both by the faculty and self-assessment by the students, is done via pass-out courses, coursework, the written qualifying event, relevant aspects of the research qualifying event, progress throughout students' thesis research, content of the thesis, and the thesis defense.

The second program objective, regarding research preparation, is addressed in part through our formal curriculum via ”Topics in Modern Research” (PHYS 515), ”Responsible Conduct in Research for Physical Scientists” (PHYS 590), and ”Special Investigations” (PHYS 990) in addition to the preparation students receive in their research groups. The committee makes several recommendations (including adjustments to PHYS 515 and PHYS 990) to ensure that our program allows us to meet this objective. Assessment of this objective, both by the faculty and self-assessment by the students, is done via PHYS 990, coursework (particularly in advanced electives), throughout students' research by advisors, and via the thesis and thesis defense.

The third program objective, regarding preparing our students as educators and communicators, is addressed via our TA training, which is supplemented by courses and seminars offered through the Center for Teaching and Learning. There are, additionally, groups on campus, such as the Yale Science Diplomats[2] that provide communication and advocacy training for students who want to develop in those areas. Additionally, our committee makes recommendations, such as the suggested revamping of PHYS 515 and PHYS 990, that could contribute to this learning objective by better training our students in giving research presentations. Assessment of this objective is done via evaluation of students' work as TAs, the research-based oral qualifying event, presentations given over the course of student research, and the thesis and thesis defense.

[2] https://sciencediplomats.sites.yale.edu

The fourth program objective, regarding equity, diversity and inclusion, and the assessment of this objective, is addressed in the department's draft EDI plan (the Oct 15, 2020 version has been submitted to the university administration[3]). This document is expected to continue to evolve with the engagement of the full department, though it already includes an action plan in support of this program learning objective. Each of the recommendations in that document (1-5) and the vision statements (1-7) would be in support of our equity, diversity and inclusion program learning objective. Additional details are available in the Appendix (A.1).

[3]https://docs.google.com/document/d/1apkg7dXR_vde1U49hjN_3eIsYnSpqNXWWRsjHwSmiNc/edit#heading=h.ttzih9myoy3

6 CURRICULUM RECOMMENDATIONS

In this section the requirements from the Graduate School are described, the current program course requirements are described, challenges related to the curriculum that were identified by the committee are presented, recommendations relating to those challenges are outlined, and additional ideas gathered through the surveys, town hall and committee discussions are provided.

6.1 Graduate School Course and Honors Requirements

The Graduate School requires the following, with respect to courses and grades:

"The course requirements for the Ph.D. degree are set individually by each department or program. Each course offered in the Graduate School counts for a single credit or, in rare cases, one-half credit. Only courses offered by the Graduate School and officially numbered on the graduate level (i.e., 500 or higher), and receiving a qualitative grade of Honors, High Pass, or Pass, can fulfill requirements for the doctoral degree, with the exception of certain undergraduate language courses or where specified in advance by the department or program. Although departments may set more stringent requirements, to meet the minimum Graduate School quality requirement for the Ph.D., students must achieve the grade of Honors in at least one full-year, two-credit graduate course or two one-credit graduate courses taken after matriculation in the Graduate School and during the nine-month academic year. The Honors requirement must be met in courses other than those concerned exclusively with dissertation research and preparation.

A student who has not met the Honors requirement at the end of the fourth term of full-time study will not be permitted to register for the fifth term. A student who is not in good academic standing with regard to course work or research, as defined by the minimum standards established by the Graduate School and the expectations outlined by the student's department or program, may be dismissed from the Graduate School. Such dismissal will be recorded on the student's transcript."[4]

6.2 Current Course Requirements

The Physics Graduate Program Requirements are provided in the Graduate Handbook[5]. Students are currently required to take (or pass-out of) the following courses, achieving a high-pass average that includes any additional electives that they opt to take:

- Five foundational courses:
  - PHYS 500 Advanced Classical Mechanics
  - PHYS 502 Electromagnetic Theory
  - PHYS 508 Quantum Mechanics I
  - PHYS 512 Statistical Physics I
  - PHYS 608 Quantum Mechanics II
- Two research seminars:
  - PHYS 515 Physics Research Options
  - PHYS 590 Responsible Conduct of Research
- At least one additional elective
- One PHYS 990: Special Investigations (SI)

6.2.1 Recent Curricular Changes (2018)

A previous committee examined the graduate program and recommended a number of changes that were adopted following positive faculty votes. The changes, along with their motivations, are listed below:

- **Reduction in number of required courses:** The number of required courses was reduced from 9 + Lab(PHYS 504)/SI to 6 + SI. This change was intended to give students more flexibility in their schedules and enable them to begin to engage in research earlier. The hope was that students would often take courses beyond this number of required classes, as would be helpful to their development as physicists.
- **Core Course Reduction:** The number of foundational required courses that students needed to take, or pass-out of with an exam, was reduced from six (CM, MM, EM, SM, QM1, QM2) to five (CM, EM, SM, QM1, QM2), with the removal of Mathmatical Methods of Physics (PHYS 506a). The hope was that students who would benefit from the Math Methods course would take it, regardless of the lack of requirement, and that this added flexibility in students' first year would enable some to engage in research at a deeper level earlier in their graduate careers.
- **Electives:** Students used to be required to choose at least one elective from a set of advanced electives, which is no longer the case.

[4] http://catalog.yale.edu/gsas/policies-regulations/degree-requirements/
[5] https://physics.yale.edu/academics/graduate-studies/graduate-student-handbook-2020

6.3 Curriculum-related Recommendations

In this section we describe the curricular recommendations for faculty consideration. For each we first state the recommendation, then provide background considerations and, as charged, comment on considerations relating to equity, diversity and inclusion. Finally, we note how the efficacy of the recommendation might be assessed.

Curriculum Recommendation 1: Return Mathematical Methods of Physics (PHYS 506a) to our list of required core courses and ensure that the links between the content of math methods and the applications in core courses are realized.

Background Considerations: We note that when math methods was removed from the list of required courses in 2018 that faculty hoped students would take the course if they found a mismatch between their mathematics knowledge and what was required for their coursework in our program. We also note that several students (first-year students in particular) reported feeling under-prepared for the mathematics in their courses. This sense was echoed by instructors in these courses. However, the students who felt mathematically under-prepared did not enroll in the math methods course. In fact, only one physics graduate student enrolled in the course in 2020. The committee therefore recommends math methods as a required course for those students who do not succeed in the pass-out exam to ensure that the students who need this instruction will receive it.

Several students in years three and beyond reported a difficulty in applying the concepts they learned while taking math methods to their other core courses, or even not recognizing the links between the mathematics they were using in their core courses and what they learned in math methods. The committee therefore includes in this recommendation that the faculty teaching math methods and the core courses work together to remedy this. Remedies could include the introduction of relevant applications as examples within the math methods course and explicitly highlighting in the core courses when concepts taught in math methods are applied. For this to occur, good communication between the faculty instructors in these courses will be critical. We note that over the past year the DGS has brought the instructors of graduate courses together for regular meetings. We encourage the continuation of this practice in support of this recommendation.

EDI Considerations: Our math methods course has the potential to bring greater equity to our program, particularly useful to nontraditional students who may have taken time off between their undergraduate and graduate careers and thus forgotten some of their prior math coursework, or students who have fewer math courses, or less rigorous courses, in their previous schooling.

Assessment of Effectiveness: The committee recommends that instructors of the core graduate courses in Classical Mechanics, E&M, Statistical Mechanics, Quantum Mechanics and relevant advanced electives be surveyed within two years of adopting this change to understand if student preparation in mathematics is well-matched to the needs in their courses. The committee recommends that students be surveyed to determine if they felt that they had sufficient curricular support for the mathematics required in our courses, and if they recognized the links between what they learned in Mathematical Methods and the math they applied in their other coursework. We note that these surveys can be informal, brief, and lightweight (via google forms, for example) and that experts from the Center for Teaching and Learning are available to help craft effective surveys.

Curriculum Recommendation 2: The requirement on maintaining a high-pass average should be restricted to only consider the seven courses on which students performed best.

Background Considerations: Faculty have noted that students are not taking advanced electives in their subfields of choice, or beyond, at the same rate as was seen in the past. Students have reported the pressure to maintain a high-pass average as the most important contributing factor to their not taking electives, or in auditing rather than taking courses for credit. This recommendation is intended to remove barriers to student exploration of electives.

The committee discussed the optimal number of courses to use for the counting of the high-pass average at some length, trying to find the right balance between providing students with curricular flexibility while also encouraging students to engage seriously with, and demonstrate proficiency in, their coursework. Agreeing that the number should not exceed our required number of courses (currently seven graded courses, which Curricular Recommendation 1 would bring to eight), but should be kept close to that number so as to not under-emphasize our core curriculum, we arrived at the number seven.

EDI Considerations: The flexibility in fulfilling this requirement will allow students with strengths in areas beyond the core curriculum to have a greater number of options for fulfilling their high-pass-average requirement. We note that that all of our students could benefit from the increased freedom to explore advanced topics without considerations of maintaining a GPA.

Assessment of Effectiveness: Evidence that this intervention has been effective should be seen in enrollments in advanced electives, normalized to student class size, though it may take several years for the impact to be measurable. If enrollments in advanced electives do not recover, and this is widely interpreted by the faculty as problematic for students' research preparation, then a return to a higher required number of advanced electives could be considered.

Curriculum Recommendation 3: Revise PHYS 515 to include a more comprehensive introduction to the various fields of physics research carried out in the department and to more formally introduce students to scientific reading, writing and presenting.

Background Considerations: In the course of the town halls, surveys, and one-on-one meetings, multiple students reported lacking a coherent overview of the areas of research in physics. While some of this was acknowledged by the students as stemming from their not attending Physics Clubs and seminars offered in the department, there was also a common thread of feedback that a lack of structure in PHYS 515, ”Physics Research Options”, contributed to the gaps in their knowledge. The committee notes that the current practice in PHYS 515, where some faculty members view the course as an opportunity to recruit students to their research groups and may therefore be less likely to participate when they are not seeking students, can result in students receiving an uneven view of research across fields in physics. The committee also notes that our curriculum does not currently devote formal instruction to the topics of reading physics research papers, or to teaching best practices in writing and presenting research.

EDI Considerations: Several students pointed to their lack of a big-picture understanding of physics research areas as contributing to feelings of imposter syndrome, which this recommendation could help address. Additionally, by having a more formal introduction to research skills in our curriculum we could equitably account for uneven instruction that students may have received in their prior educations. The implementation of this recommendation would also serve as an acknowledgement to students that research skills are not expected to be innately known, but are learned, which can help contribute to a growth mindset in our graduate program.

Assessment of Effectiveness: Student feedback following PHYS 515 as well as exit interviews (in a number of years, after students have traversed the adjusted curriculum) should enable the effectiveness of this intervention to be assessed.

Curriculum Recommendation 4: Update PHYS 678, ”Computing for Scientific Research”, to include data analysis and modeling and offer this course on a regular basis.

Background Considerations: Learning Objective 1 states a goal of providing students with ”the necessary accompanying methodological aspects of mathematics, computing, and instrumentation.” We have a course (PHYS 678: Computing for Scientific Research) that covers some of the relevant topics in computing, but this course is not offered regularly enough to serve students’ needs. The committee recommends that this course be updated (e.g., to include data analysis and modeling) and offered more regularly.

EDI Considerations: The skills that would be taught in this course are in high demand both from students who wish to pursue further academic work and from students who wish to use their talents outside of the formal academic landscape. This course provides an opportunity for the department to better support students with non-academic careers goals.

Assessment of Effectiveness: A measurement of enrollment in, and student feedback on, the updated PHYS 678 over several iterations of the course should enable this curriculum change to be assessed.

Curriculum Recommendation 5: Develop and regularly offer a new elective on the topic of instrumentation.

Background Considerations: Learning Objective 1 states a goal of providing students with ”the necessary accompanying methodological aspects of mathematics, computing, and instrumentation”, yet we do not currently address instrumentation and experimental methods in our curriculum. We note that instrumentation is a critical component of the work of experimentalists, and an understanding of instrumentation is a necessary component of the interpretation of many experimental physics results. This course could therefore benefit both experimenalist and theory students in the department, and might also attract students in related departments on campus.

EDI Considerations: An instrumentation course could help those students with strengths in experimental techniques, who reported in surveys and one-and-one meetings that they often feel undervalued in our current program, by giving them an opportunity to excel and advance in their areas of interest early in their graduate careers and in the formal context of a course.

Assessment of Effectiveness: A measurement of enrollment in, and student feedback on, an Instrumentation course over several offerings of the class should enable this curriculum change to be assessed.

Curriculum Recommendation 6: : Restructure Phys 990, ”Special Investigations” (SI), modeled after Phys 470/471 with an overall course instructor who provides oversight and direction for the students enrolled.

Background Considerations: PHYS 990 is an important component of our graduate program, but more oversight would help ensure that we successfully provide all students with worthwhile exposure to, and experience in, research. There is currently little consideration paid to expectations or grading for the course. While some consistency would be useful, there is also a desire to keep substantial flexibility. We want students to be able to freely explore their research interests without building in expectations that can only be met with prior experience. Additionally, there is substantial variation in what an early-stage research experience might consist of across our fields of research, and instructors should have the flexibility to introduce students to their fields without standardizing expectations to the point where this diversity isn't supported.

There is significant experience in the department with organizing undergraduate research experiences through the courses PHYS 470/471, where a balance between student and instructor autonomy and overall structure is nicely achieved. Shifting to this model for PHYS 990 would mean:

- An overall instructor appointed to the course would approve of the SI proposals, alleviating the DGS of this burden.
- The instructor would hold a meeting with the group of students enrolled in the SI early in the semester, as is often done in the case of PHYS 470/471, to establish expectations and connect students with needed resources. This should include a discussion of best practices in research presentations and pointers to additional resources on this topic.
- A brief, informal mid-term progress report would be produced by the student, providing an opportunity for oversight both by the overall instructor and the PI serving as mentor early enough for any needed course-corrections to be made.
- A final report would be submitted, which builds on the mid-term report.
- A final presentation would be given with the PHYS 990 instructor and research supervisor present and PHYS 990 class invited. Further details are provided in Section 7.3 below, in the recommendation for a research-based qualifying event. (Note that in the case of exceptionally large PHYS 990 class sizes that additional faculty may need to assist the instructor to cover all presentations.)
- Course grading would become more uniform, though grades would likely remain quite high (as is seen in PHYS 470/471). The instructor of the course would be responsible for entering the course grades, but the decision regarding the grade would be made in consultation with the supervising faculty member.

EDI Considerations: Additional consistency and attention, suggested with this recommendation, will improve equity across the curriculum.

Assessment of Effectiveness: The students who enroll in PHYS 990, as well as the faculty who supervise them, should be surveyed to determine whether the additional structure is useful, and whether it is lightweight enough to enable needed flexibility for the student and research supervisor. Additionally, PHYS 990 will be linked to the department qualifying event. Enrollment in PHYS 990, and correlation with student year, should be tracked to ensure that students do not postpone taking PHYS 990 due to the link with a qualifying event, to ensure that this course continues to be a way for students to explore research opportunities early in their graduate careers, including in areas where they do not have previous experience.

Curriculum Recommendation 7: The Department should examine the course requirements for PEB students to look for potential overlap with Physics coursework with an eye toward possible reduction of Physics requirements for these students.

Background Considerations: A number of our students are enrolled in Yale's integrated graduate program in Physics, Engineering, and Biology (PEB).[6] These students have additional requirements beyond what is required from the physics graduate program, that must be completed by the end of their second year of graduate school. These additional requirements include:

- A one-semester required workshop titled "Integrated Workshop" that "exposes incoming PEB graduate students to a range of qualitative methods and approaches used to study biological problems, develops communication skills across the disciplines, and ensures that incoming students feel part of the PEB community right from the beginning."
- Two courses that are optional, intended to fill potential gaps in students undergraduate backgrounds: "Boot Camp Biology for Physicists and Engineers" and "Quantitative Approaches in Biophysics and Biochemistry". We note that the majority of physics students in PEB do not take these courses.
- A required 0.5 credit course, "Methods and Logic in Interdisciplinary Research" that introduces integrated approaches to research.
- A required 1 credit course, "Biological Physics", which is "an introduction to the physics of many important biological phenomena, including molecular motors, protein folding, bacterial locomotion and allostery."
- A required 1 credit course, "Modeling Biological Systems II", which covers "advanced topics in computational biology and the techniques used to integrate knowledge from mathematics, physics, and engineering into the analysis of complex living systems as dynamical systems".

Students in the PEB program reported to the committee that they find it challenging to simultaneously fulfill the Physics and PEB course requirements. The committee recommends that the graduate program consult with biophysics faculty in our department and across the PEB program to discover if a reduction in requirements can be made for PEB students without damaging their physics or PEB-integrated educations. If potential reductions in requirements are found, this could be brought before the faculty for consideration. We also recommend a study to be undertaken to compare the number of courses taken by PEB students with the number of courses taken by non-PEB students in the physics graduate program.

EDI Considerations: Currently, PEB students have reported that they do not feel that they are treated equitably due to

[6] https://peb.yale.edu/curriculum

the significant difference in requirements that they face when compared with other physics graduate students. It is therefore important for the department to understand whether or not this difference in requirements is required for PEB student training.

6.3.1 Additional Curricular Considerations

There were several curriculum changes discussed that did not rise to the level of recommendations that the committee includes here for completeness and in case of future curricular reviews:

- In the course of our work there were concerns raised by students and faculty members with respect to potential gaps in the graduate program curriculum, particularly in the area of advanced electives. A thorough survey of course offerings and student needs could be carried out to identify these gaps.
- The committee considered a recommendation that would make attendance at the weekly department Physics Club mandatory for students early in their graduate careers. This idea did not have sufficient support across the committee to advance to a recommendation due to concerns of the accessibility and quality of Physics Clubs and concerns of potential over-reach in our recommendations. However, it was widely agreed that the current poor attendance in Physics Club, both by students and faculty, points to a missed opportunity for education and community building across our department.
- Attention should be paid to the enrollment in advanced electives to understand if the adjustment to the high-pass average requirement (Curricular Recommendation 2) results in students taking these courses or if further changes are needed. Research advisors can play an important role in this by encouraging the students they mentor to take advanced electives that are relevant to their research fields.

7 QUALIFYING EXAM RECOMMENDATIONS

In this section we describe the graduate school requirements for the qualifying event, the current Physics Department Qualifying exam, as well as the committee recommendation for the qualifying exam moving forward.

7.1 Graduate School Requirement

The graduate school requires the following regarding the Qualifying Exam:

Each Ph.D. student must pass a general examination, separate from course examinations, in the major subject offered and in such subordinate subjects as may be required by the department. Such examinations are described in the individual department listings. Students should consult with their director of graduate studies for further information about this requirement.[7]

7.2 Current Qualifying Exam

The Current Yale Physics Qualifying Examination consists of four parts that are graded and passed (or failed) separately, with two questions on each part. The content of the exam draws from the list of topics provided in the Appendix (A.2). The parts are:

1. Classical Mechanics
2. Electricity & Magnetism
3. Quantum Mechanics
4. Statistical Mechanics

Students are permitted two opportunities to pass the exam, though entering students may take any parts of the exam at the beginning of their first year without the attempt counting as one of the student's two opportunities. The exam must be taken for the first time no later than the beginning of a student's third semester.

To create, administer, and grade the Qualifying Examination, a committee will be established by the Chair of the Physics Department. Students taking the examination will remain anonymous to the committee and to the faculty (except the DGS) until the results of the examination are accepted by a vote of the faculty.

If a student fails any part(s), then they only need to retake those part(s) in their next attempt. Students who do not pass all four parts of the Qualifying exam by the beginning of their second year can request to take an Oral exam after 2-3 months, for the part(s) that they failed. Alternatively, students may opt to retake those part(s) of the written Qualifying exam at the beginning of their third year. If a student does not pass the exam after two attempts (either written or oral), the faculty can decide to offer the student an oral exam, and if completed successfully, the student can proceed to candidacy. More details are available in the Graduate Student Handbook.[8]

7.2.1 Recent Qualifying Exam Changes (2018)

A previous committee examined the graduate program and recommended a number of changes to the qualifying exam that were adopted following positive faculty votes. The changes, in large part introduced to reduce student stress, are described below:

- The list of topics covered on the qualifying exam was significantly reduced
- The exam was modified from occurring in two parts (CM+EM+MM and SM+QM) to four independent parts (CM, EM, SM, QM) each with a separate test.
- The time allotted per section of the exam was increased from 2 hours to 2.5 hours
- Students were permitted an option to take an oral exam after 2-3 months on the section(s) they failed, with faculty tutoring offered, rather than needing to wait a full year for the next iteration of the exam.

7.3 Qualifying Event Recommendation

The committee recommends a fundamental shift in how the department fulfills the University's qualifying requirement from a "pass/fail high stakes qualifying exam" to a "qualifying event", which serves as a learning opportunity that students pass by nature of participating in the process.

Background Considerations: There are multiple reasons for the committee's recommendation:

- There is evidence in the literature, in our department, and in departments across the country that high-stakes tests–and high-stakes pass/fail exams in physics graduate programs in particular–have a disproportionately negative impact on populations that are under-represented in graduate school in physics. This spans from the stereotype threat that can be activated in taking the test, to the additional burden that some students might feel in "representing" some aspect of their identity for the department, to the strong negative reaction that students who are not initially successful might have who already feel a tenuous sense of belonging. The committee therefore finds the continuation of a high-stakes pass/fail test to be inconsistent with our values and program learning objectives.

[7] http://catalog.yale.edu/gsas/policies-regulations/degree-requirements/

[8] https://physics.yale.edu/academics/graduate-studies/graduate-student-handbook-2020/academic-requirements#QualifyingExam

- In our many and varied discussions surrounding possible qualifying events, the committee was unanimous in wanting the event to support student learning and development. The shift from a pass/fail framework to one that instead provides constructive feedback in support of student learning can help students experience the event as a learning opportunity rather than a hurdle.
- While the current qualifying exam is a pass/fail event that students must pass in order to continue in our program, it is so rarely used to remove students from the program that this aspect of the qualifying exam can be considered an empty threat that nevertheless causes student stress without adding function to the program.
- Finally, this shift communicates that the Yale Physics Department expects that students who matriculate here can be successful in our program, and that we are eager to work in support of student growth.

With this recommendation established, the committee spent a significant amount of time discussing how the qualifying event could best map to our proposed program learning objectives. There is a wide range of opinion among our faculty and students regarding which aspects of our program are most in need of this support. This wide range of opinion was voiced by committee members and was reflected in the feedback we received. After much discussion we arrived at a recommendation that represents a super majority of the committee.

We recommend that the qualifying event be in support of learning objectives 1-3, crafted with the lens of learning objective 4. The recommended event builds on current experience in the department and occurs in two stages: (1) students will have an opportunity to review their foundational course content and (2) students will engage in a guided research experience and practice giving a research presentation early in their graduate careers. The details of these two events, in which all students are expected to participate, are provided below.

(1) Foundational Knowledge Event

The department has significant experience with a qualifying exam that addresses student foundational knowledge. We heard from many students that the experience of preparing for and passing the exam was an important component of their education. However, there are a number of deficiencies with the current exam that need to be addressed in the transition to a qualifying event:

1. The current exam is a high-stakes, pass/fail exam with all of the associated drawbacks outlined above.
2. Students who do not pass the exam have the option to have a follow-up oral exam within several months or to re-take the test the following year. Both of the these outcomes delay their full engagement with research.
3. The current exam leads to an instant bifurcation of the class, with some students passing it on entry. This separates the cohort in ways that damage the sense of community among the class and it reduces the opportunities that the students have to learn from each other as they study together. We heard from some students that this initial split led them to question their abilities and belonging from their first weeks in our program.
4. One of the goals of the current exam is to provide students with the opportunity to study a broad range of subjects together, which can help them make connections across topics. However, the current implementation allows the exam to be taken in a fractured way, with four components that can be taken in different years.

The committee recommends a foundational knowledge qualifying event that all students take as a cohort at the beginning of their second year. The objectives of the event would be to provide an opportunity for students to **review** and **consolidate** their understanding of the core curriculum; have the opportunity to **extend** their understanding by studying with their peers under the tutelage of senior graduate student mentors if they emerged from the core courses with gaps in their knowledge; and to further **learn** this content in the process of correcting their errors. Additionally, some faculty, particularly in theory, use student performance on this event to inform their choice of students for their research group.

The format of the event would borrow from the existing qualifying exam (range of topics, number of questions, level of problems, time allotted, etc.) The students' work would be marked, with gaps and errors indicated, and returned to the students. A grade would be assigned, but this grade would only be viewed by the faculty. The students would then correct their mistakes over the course of the following week, with one-on-one access to the senior graduate student mentors who helped with review sessions over the summer, and return their corrected problems to the qualifying committee, thereby completing this qualifying event.

(2) Research-based Event

During the course of our discussions there was broad agreement across the committee that our research learning objectives were not supported strongly enough across our curriculum, including the critical skills of scientific writing and presentations. A number of the curriculum recommendations address this, through modifications to PHYS 515 and PHYS 990 in particular.

The committee feels that the importance of research, including the dissemination of knowledge, should be acknowledged by the designation of the research presentation in the revised PHYS 990 proposal being considered the oral, research-based component of our department qualifying event. The objective of this event is **to provide students with a guided research experience early in their graduate careers, and an accompanying opportunity to present that research and receive**

written feedback. The skills necessary for research can continually be improved upon, and the emphasis of this experience should be on a growth mindset that provides all students constructive written feedback, using a standard form filled out by the PHYS 990 instructor and research supervisor, on their strengths and suggested areas of focus for future improvement. The qualifying event consists of the completion of a presentation of the PHYS 990 project and reception of this written feedback. We note that the PHYS 990 experience may, or may not, be in the area of a student's eventual thesis work.

The presentation is suggested to be run as follows:

- The first approximately 10 minutes of the presentation should introduce the field in which the research occurs, describing several current open questions or recent relevant developments.
- The next approximately 15 minutes would be dedicated to the student's work.
- This would be followed by a brief Q&A.
- Written feedback from the PHYS 990 instructor and supervising PI will be provided.

There is no expectation that students will have fully mastered the art of the research presentation, understood the scope of all open questions in their field, or even fully understood all aspects of their ongoing research questions at this early stage of their careers. This experience is intended to provide them with an opportunity to practice a research presentation with lower stakes than a conference or thesis presentation, and an early opportunity to think more broadly about a field, and how a particular research question is situated in that field. The Q&A and feedback should be conducted in the context of supporting intellectual curiosity, and it is the responsibility of the faculty members involved in this event to establish and foster a learning environment for the presentation and to ensure that the written feedback provided is constructive.

The preparation for this event occurs in the context of the PHYS 515 course, during which best practices in research presentations would be discussed, as well as in PHYS 990 itself, during which this topic will also be addressed. The committee additionally strongly recommends that graduate students be encouraged to attend all of the department Physics Clubs and additional seminars in their fields of interest so that they have access to many examples of effective (and likely in spite of our attempts to ensure quality, but perhaps just as instructive, ineffective) research presentations.

Timing Considerations for the Qualifying Events

Students must satisfy the University's Qualifying Exam requirement before they advance to candidacy. The committee discussed the optimal timing of the recommended qualifying events, with the following **considerations for the written qualifying event:**

- The removal of the pass/fail line makes the "free attempt" version of the written qualifying event, which used to be offered at the beginning of students' first year, less appropriate. This is not only because the objective includes having students review their core course subjects, but also because there are benefits to having the students prepare for the event as a cohort. This points to the first opportunity for the event occurring after the students' first year.
- There was agreement among committee members that the summer between 2nd and 3rd year should be dedicated to research in order for students to advance through our program in a timely manner, which suggests that the written event should not occur as late as the fall that begins the students' 3rd year.
- It was noted that students will not necessarily have completed all of the courses that contribute to written qual topics in their first year. The relevant courses are Classical Mechanics, Electromagnetism, Statistical Physics, Quantum I, and selected topics from Quantum II. In the past few years, it was a fairly common occurrence for some students to have not taken Quantum II before their first try at the qual, but this was mitigated by the option for students to have another attempt before their 3rd year, or a follow-up oral exam. As we move to the "one attempt" written qualifying event, students would not have the 3rd year fall-back option. However, due to the problems with delaying the event to the beginning of a 3rd year (in interfering detrimentally with research progress), we note that some students who go through this process will be experiencing some of the covered material as more of a "pre-test" than a "post-test". There are benefits to engaging in a pre-test. The experience of studying the subjects could help students prepare for the courses that they didn't take in their first year. However, students, and any faculty who view student performance on this event, should keep in mind the fact that some students are solving problems on material that they have not been taught. This has a significant impact on how performance on the event should be interpreted.

The outcome of these discussions was to place the written qualifying exam at the beginning of students' 2nd year. This means that the majority of students will have just finished, or be about to take, courses on the topics that they encounter in the written qualifying event.

The committee also considered multiple issues relating to the **timing of the research-based oral event**:

- There was a desire to place this event early in students' graduate careers, if possible before students give conference presentations, so that they have the opportunity to practice and get feedback on presenting research in a low-stakes setting.
- There was a desire to keep this research presentation decoupled from students' thesis work to avoid complications if students take some time to identify their thesis advisor, or switch from one group to another.

- There was a desire to keep the additional burden on students low, which the link to PHYS 990 helps with, since students are required to engage in this research experience already in our curriculum.
- There was a desire to keep the additional burden on faculty low, which the link to PHYS 990 helps with, since the PHYS 990 instructor could handle the logistics of the presentations as well as oversee uniformity in terms of the feedback provided.
- There was some concern expressed that students might postpone taking PHYS 990 if it were linked with a qualifying event, preferring to gain experience before their presentations. The committee hopes that the nature of the event, which is not graded or pass/fail, helps allay any student concerns with taking PHYS 990 as early as their first year, if this fits best with their optimal course of study.

The outcome of these discussions was to associate the oral, research-based qualifying event with PHYS 990 with the expectation that students would take this course at some point in their 1st or 2nd years of the graduate program.

COVID-19 Considerations and Transitioning the Qualifying Events

In the fall of 2020 the qualifying exam was canceled due to COVID-19 restrictions, so there is a group of students that did not have the opportunity to fulfill this graduate school requirement. Additionally, there are considerations concerning the fact that some students have already fulfilled their SI experiences, but have not yet fulfilled the qualifying event requirement.

Qualifying Event Recommendation 5: We recommend that the first holding of the new, non-pass/fail written event should occur in the fall of 2021 and that the DGS and graduate program director will work together to schedule oral research presentations, with the first modified running of PHYS 990 recommended for the 2021-2022 academic year.

The following categories of cases are meant to address questions of implementation in the transition period.

- All students who have passed the department qualifying exam in all of its parts are not expected to fulfill any of the requirements outlined in the qualifying event sections above.
- For those students who have passed some number of the four categories of the qualifying exam, they would only participate in the qualifying event on those foundational topics that they have not passed. While this does not allow for these students to review the body of material as a whole, this exception seems to be necessary to be fair to the successful efforts already undertaken by these students.
- For those students who have not yet passed the foundational qualifying exam, and therefore will participate in the qualifying event, but who have already taken their SI (PYHS 990), they will have the opportunity to give a research presentation either on the work of their SI, or on ongoing research, following the description of the SI presentation provided in the curriculum recommendation above. This exam will be scheduled in consultation with the graduate program director.

7.3.1 Additional Qualifying Event Considerations

The committee discussed many ways to satisfy the graduate school requirement of a qualifying event, considering more than a dozen options. In the course of these discussions we were able to see pluses and minuses associated with each potential qualifying event, including in the event we bring forward as our recommendation in this report. For completeness, we describe some of the themes that emerged, along with answering other components of our charge, below.

Different Qualifying Events by Subfield: Our charge asked the committee to examine "whether different qualifying exams based on subfields should be considered." In order to gauge faculty support for this idea, we asked the following question on the faculty survey: "Should all graduate students in a given year take a qualifying exam that is identical in form, or do you think that differences in the nature of a qualifying exam (written vs. oral or research-based vs. curricular) would be acceptable for different cohorts depending on the views of the advisor?" In our 23 survey responses there was only one response in support of this idea, and one response registering "no opinion", with the rest of the responses indicating a preference for a uniform qualifying event across all students. The committee therefore did not pursue this possibility further. We note that important motivation for accepting or rejecting a potential qualifying event format could be centered on concerns related to equity, diversity and inclusion, so if the department were to go the route of different events per sub field, we would want to ensure that each event were consistent with our values. Additionally, we discussed the benefits to students that comes with meeting similar expectations in that students could study and work together.

Grading a written exam: The committee recommendation includes the grading of the written qualifying event with the grade shared with faculty, but not students, since these grades were helpful to some faculty members in selecting students for their research groups. There were concerns expressed that grading a written exam, even if these grades are not shared with students, could negate some of the benefits of moving to a non pass/fail test. For example, students could experience heightened stress knowing that faculty would see grades, and for those who felt that they did poorly this experience might work against their sense of belonging in the program.

Ensuring uniformity in an oral presentation and Q&A: One of the concerns that emerged with including an oral exam as part of our qualifying event was how to ensure that implicit or explicit bias did not result in unfair treatment of our students. The prior experience within the department of an oral field exam, which faculty on the committee reported was ended in part due to uneven treatment across the department and the difficulty of making the experience uniform. There is a tension from the equity perspective between wanting to be fair by providing some uniformity to students, but also wanting to avoid activating stereotype threats by having a standardized test format. (See the following section.)

The tension between standardized tests and EDI concerns: Standardized tests invite comparisons between students, are known to activate stereotype threat, and can result in further isolation of students from under-represented groups in our program.

The level of questions on a written exam: There was some discussion regarding the level that is appropriate for questions in a written qualifying exam. Other departments make a range of choices here, from explicitly undergraduate-level questions to graduate-level questions. There is a sense among students that the current Yale exam is intended to be ”easy”, which could exacerbate student concerns if they do not do well. However, members of the committee who make the exam have noted that the exam is meant to be straightforward, meaning not containing tricks, but that it is not ”easy.” There were suggestions raised that the change of the test to non-pass/fail could present an opportunity for the test questions to be made more challenging, but the committee did not arrive at a recommendation on this point.

Potential redundancy in our program: The concern was raised that the foundational knowledge is taught and assessed through our courses, and that having a qualifying event also focused on this could over-emphasize this aspect of student training and reinforce a sense of not-belonging among students for whom course work is not their strength. Some faculty members were concerned that a lack of standardization across the graduate courses left a gap that the written qualifying event could fill. The committee commends the work initiated by the DGS to bring the graduate course instructors together regularly, and recommends that these meetings continue since they can positively contribute to the coherence of the curriculum in our program.

Student support when correcting written qual answers: There is concern that students will not be sufficiently supported when working on corrections to their written qualifying exams. A suggestion was made that students be provided the solutions when their tests are returned. This would eliminate the need for students to be isolated or inferior when working on their corrections, and is something to consider for the future.

Avoiding superficiality in a research-based oral exam: There were some suggestions that students should present research results, such as contemporary work resulting in Nobel or Breakthrough prizes for their research-based oral qualifying event. The hope was that this kind of event could expose students to research in a range of fields early in their graduate careers. However, concerns were expressed that students could lack the background needed to truly understand and engage with results, particularly those that are not in their areas of interest, and before they have taken the relevant advanced electives. The committee recommendations therefore resulted in focusing on the students' own research projects for their research-based oral presentations.

Student Workload: The committee considered the workload demands on students that any qualifying event proposal would bring. We heard repeatedly from students that the justification and objectives for qualifying events were critical to students buying in to the event, and that they were not concerned with challenges or hard work that was well justified. The committee recommendation adds corrections to a written qualifying event and a more formal research presentation to the student workload. We believe that both of these additions are well-motivated based on the program learning objectives.

Faculty Workload: The committee was aware of the workload demands on the faculty of the qualifying event proposals that were considered. With the written qualifying event on fundamental physics topics, there is a committee, guided by a committee chair, that crafts the test, iterating to make sure that the level of the problems are appropriate. This committee also marks/grades the tests. The work of determining a pass-fail recommendation would no longer be on the committee. The research event considered builds on the curricular recommendation for PHYS 990, which has a faculty member assigned. Given that the SIs are already meant to result in a presentation, this does not add too much of a load to the department since research supervisors were already doing this work. The feedback on the midterm written report, final written report, and feedback on the presentation are all additional work that the department would need to support, largely carried by the PHYS 990 instructor and research supervisor.

A APPENDIX

A.1 Expansion of Learning Objectives

The Graduate Program Learning Objectives are described in the main body of this text. In this appendix section we provide additional detail surrounding these objectives, along with feedback we received from the students and faculty (via a student town hall, discussion in faculty meetings, a survey sent to students, a survey sent to faculty, and various one-on-one meetings with members of the department.) The hope from the committee is that this information could be useful if the department examines the program learning objectives in the future.

Learning Objective 1

This learning objective, ”Students will acquire a general foundational knowledge of physics at the graduate level and the necessary accompanying methodological aspects of mathematics, computing, and instrumentation”, was explored further by the committee.

The committee presented this statement: ”Physics is a foundational science in which knowledge is often built sequentially.” We received the following graduate student and faculty feedback:

- Some people pointed out that, given the stops and starts and work in unfruitful directions that acquiring physics knowledge can often be an iterative, rather than sequential, process.
- An additional point was made that we often have measurements made that we do not understand, pointed to this fact as justification for physics not being ”fundamental.”
- It was noted that we do not acknowledge anywhere in the learning objective, or this point in particular, that our program builds on the base of knowledge that students gain as undergraduates.
- It was noted that physics is not a ”base of knowledge”, but rather ”a set of skills and a way of thinking.”

Another statement presented by the committee, in an attempt to guide us toward developing our core curriculum, was ”Many disciplines within physics build from a shared base of knowledge, which includes the subjects of Classical Mechanics, Quantum Mechanics, Electromagnetism, Statistical Mechanics.” We received a lot of feedback from faculty and students on this:

- Several people pointed out that general relativity, one of the most important theories of the past century, was (strikingly) missing from the list.
- Quantum field theory was also noted as missing.
- It was noted that this list could have been written decades ago, and there was concern regarding the implication this list might give that physics is a static discipline, and that with it we are simply perpetuating the past.

The committee presented this statement: ”Working with these subjects requires tools from mathematics (complex analysis, linear algebra, probability theory, etc.), statistics, and computing.” We received the following comments:

- The importance of ”concepts” rather than a focus on ”tools” was noted.
- Similarly, the focus on “tools” was described as ”strange”, because it implied a “repository of techniques” rather than a “mastery of subjects”
- It was noted that many experimental/instrumentation skills were missing.

Learning Objective 2

This learning objective, ”Students will learn to identify and solve problems at the frontier of physics knowledge, uphold standards of scientific integrity, and disseminate their research”, was explored further by the committee. Our additional thoughts, and feedback we received, are provided below.

The Committee presented the statement, ”Critical thinking and foundational methods in physics are key components in research in many academic and professional fields.” We received feedback that ”creativity”, in addition to ”critical thinking” was essential. We also received an alternative suggestion for a description of how physics evolves: ”Physics evolves through theoretical, experimental, and analysis advances, and in particular benefits from the intersection of all three.”

Learning Objective 3

This learning objective, ”Students will become educators and communicators with the ability to promote an understanding and appreciation of physics across the university and in society”, was explored further by the committee. Our additional thoughts, and feedback we received, are provided below.

The committee presented the statement, ”Successful researchers must be able to communicate their results through papers and presentations on their research results, and write proposals seeking support for future research directions.” We received several comments as feedback:

- Many people noted that our current curriculum largely does not currently train our students in communication.
- It was noted that students do not typically work on grant applications and that even some faculty do not rely heavily on grants.

- There was concern expressed that the focus on communication was misplaced, and that people can be effective scientists without being successful educators or communicators.
- It was noted that this detailed focus on the job of faculty members might push our program to focus too much on training future professors, when this was not the goal of all of our students.

Learning Objective 4

This learning objective, ”Department members and students will work together to develop and realize, in the department and in the community, progress and success in diversity, equity, and inclusion in all aspects of the scientific enterprise”, is addressed in the department equity, diversity and inclusion plan, as noted in the text above. In this section we point out the recommendations and vision statements in that document that are particularly important in supporting this learning objective.

The first recommendation in the EDI document[9] is to ”continue work underway, and measure its impact.” Two components of the work already underway that are critical for this learning objective are the continuation of the department Climate and Diversity committee, which includes graduate student members in addition to having other department constituencies present. This is a clear example of a way that faculty and graduate students can learn from, and work with, each other. Additionally, the creation of the Graduate Student Advisory Committee, which meets regularly with the DGS, Graduate Program Director and Department Chair is another critical step forward in the department, keeping lines of communication open so that concerns related to EDI can be communicated and addressed.

The second recommendation, to ”change our demographics, make physics accessible to all” is applies to recruitment at the student postdoc, faculty and staff levels. A more diverse graduate class, supported by a more diverse faculty, within a department holding ongoing conversations related to issues of equity, diversity and inclusion will support this EDI learning objective.

The third recommendation, to ”deepen our mutual respect and increase everyone’s engagement in our work” is also critical for the advancement of this program learning objective, particularly given that we want to think about ”all aspects of the scientific enterprise.” The recommendation includes the vision to support EDI work, to be anti-racist, to promote transparency and accountability, and to promote inclusive research, teaching, and mentoring, which are critical components of this program learning objective.

The fourth recommendation, to ”do the work, without ceasing” speaks to the willingness of the department to not put EDI work on the back-burner, but to instead retain focus on it, and prioritize the work in the department. This commitment ensures that the work in support of this learning objective will continue to be a foundational component of our department.

[9] https://docs.google.com/document/d/1apkg7dXR_vde1U49hjN_3eIsYnSpqNXWWRsjHwSmiNc/edit#heading=h.ttzih9myoy3

A.2 Topics Covered in Current Yale Physics Qualifying Exam

The following is the list of topics covered in the Yale Physics Qualifying Exam as of August 2018[10].

Classical Mechanics

Newtonian Dynamics: Newton's laws, Conservation laws
Lagrangian Dynamics: Generalized coordinates, D'Lambert's principle, Lagrange's equations, Hamilton's principle of least action, Symmetries and conservation laws (Noether's theorem)
The two-body central force problem: Reduction to the one-body problem, Effective potential, Kepler's problem, Classical scattering
Small Oscillations: Equilibium and linearization of the equations of motion, Normal coordinates and normal modes
Rigid-Body Motion: Angular momentum and kinetic energy, Inertia tensor, Euler's equations, Euler angles, Compound pendulum, symmetric top
Special Relativity: Lorentz transformation, Relativistic kinematics, Relativistic dynamics
Hamiltonian Dynamics: Hamilton's equations, Poisson brackets, Symmetries and conserved quantities, Canonical transformations and generating functions

Electricity and Magnetism

Electrostatics: Electric field and potential, Gauss's LawSurface charge distributions, Poisson's and Laplace's equations, Electric field in matter and dielectrics, Multipole expansion
Boundary-value problems: Method of images, Separation of variables, Orthogonal functions and expansion, Spherical coordinates and spherical harmonics, Legendre functions, Cylindrical coordinates and Bessel functions
Magnetostatics: Magnetic field and vector potential, Ampere's law, Magnetic moment, torque, Boundary-value problems, Magnetic fields in matter
Electrodynamics: Faraday's law of induction, Energy in a magnetic field, Maxwell's equations, Poynting's theorem, Lorentz transformation of fields, Four-tensor formulation of Maxwell's equations
Electromagnetic waves: Plane waves, Polarization, Energy and momentum in electromagnetic waves
Radiation: Dipole radiation, Power radiated by a point charge

Statistical Mechanics

Thermodynamics: Thermodynamic equilibrium, The first and second laws of thermodynamics, Entropy, Thermodynamic potentials, Third Law of thermodynamics
The Principles of Statistical Mechanics: Statistical distributions and classical statistics, Density matrix and quantum statistics, Liouville's theorem, The Microcanonical ensemble, Entropy in statistical mechanics, Second and third laws in statistical mechanics
The Canonical and Grand-canonical Ensembles: Gibbs distribution, The partition function, Equipartition theorem, The grand-canonical ensemble, Fluctuations in equilibrium
Identical Particles: Classical ideal gas of identical particles, Maxwell-Boltzmann distribution, Quantum ideal gas of identical particles, Fermi gas and Fermi-Dirac statistics, Bose gas and Bose-Einstein statistics, Bose-Einstein condensation, Photons and black body radiation, Phonons

Quantum Mechanics

Quantum Kinematics and Dynamics: Postulates of quantum mechanics, Configuration space vs. Hilbert space, Wave function vs. state vector, Time evolution in Schrodinger and Heisenberg pictures, Uncertainty principle
Simple 1D Problems: Particle in a box, Free particle, Delta function potential
Harmonic Oscillator: Eigenstates and spectrum, Raising and lowering operators
Symmetries: Continuous symmetries (translations, rotations), Discrete symmetries (parity, time reversal)
Angular momentum: Orbital angular momentum, Spin, Angular momentum algebra, Rotation group, Tensor operators, Addition of angular momenta
Hydrogen atom
Charged particle in a magnetic field
Approximation methods: Time-independent perturbation theory, Time-dependent perturbation theory, Variational methods

[10]https://physics.yale.edu/sites/default/files/files/Topics for the Qualifying ExaminationForAugust2018 (1).pdf

A.3 Qualifying Exam Descriptions: Physics Programs

This section provides additional documentation regarding the various qualifying exams in other physics departments, with their references. Note that there can be changes from year to year and that this information is current as of January, 2021.

MIT: ”The Written Exam consists of two problems in each of four areas – quantum mechanics, statistical mechanics, electricity and magnetism and classical mechanics. Demonstration of core competence in all areas may be achieved in one of two ways. A student may pass each area either by passing one of the two problems on the Written Exam, or by completing the corresponding graduate-level course (for classical mechanics, 8.309; for quantum mechanics, 8.321; for statistical mechanics, 8.333; for electricity and magnetism, 8.311) with a grade of B+ or higher.

The purpose of the oral portion of the general exam is to test students' broad general knowledge within their field. The student's field is determined by that of his or her research supervisor. (Students with supervisors outside of the department will be examined in the research field of the co-supervisor. For the purpose of the Oral Exam, the co-Supervisor will be considered the “research supervisor” in the committee structure outlined below.)

The designated Committee Chair for each field will host a meeting of examinees at the start of each term to review exam expectations. The first question will be in the student's specific area. The student's committee chair will provide this question at least one week prior to the examination. Under normal circumstances, the chair will ask the research supervisor to suggest a question to be used for this purpose. The oral examination will continue in the student's general field. Discussion of a student's research, when applicable, will comprise no more than the final quarter of the examination.

The oral exam committee consists of the chairperson and two other faculty members. Each research field will appoint one committee each year to examine all students within that field. If a student's research supervisor is a member of the standing committee, he or she will be replaced by an alternate faculty member for that exam only. The research supervisor may observe the exam and provide input if solicited by committee members. The supervisor and student will be asked to leave the examination room when the final decision is discussed. The first attempt at the oral exam must be made by the first term of the third year. Two attempts are permitted with the second attempt, if necessary, scheduled in the subsequent term. (If the subsequent term precedes the third year, a student may postpone the second attempt until the beginning of the third year.)

Currently, oral exam committees are formed in each of the following fields:

Astrophysics, Nuclear and Particle Experiment, Atomic and Optical Physics, Nuclear and Particle Theory, Biophysics, Quantum Information, Condensed Matter Experiment, Plasma Physics.”[11]

Stanford: ”The Qualifying Exam is an important part of the process of admission to candidacy. The oral exam seeks to give the student an opportunity to exhibit a broad knowledge of physics an in-depth understanding of a particular area of physics that is not the one of her/his thesis research. The student should exhibit command of the material, an ability to extract the essential elements of a relatively recent development in physics, and the capacity to present this material to an audience of general professionals in a way that demonstrates his or her expertise. It is required that students schedule the exam for the Spring quarter of their second year.”[12]

Cal Tech: ”Written Candidacy Exam: Physics students must demonstrate proficiency in all areas of basic physics, including classical mechanics (including continuum mechanics), electricity and magnetism, quantum mechanics, statistical physics, optics, basic mathematical methods of physics, and the physical origin of everyday phenomena. A solid understanding of these fundamental areas of physics is considered essential, so proficiency will be tested by written candidacy examinations.

No specific course work is required for the basic physics requirement, but some students may benefit from taking several of the basic graduate courses, such as Ph 106, Ph 125, and Ph 127. In addition, the class Ph 201 will provide additional problem solving training that matches the basic physics requirement.

Exam I: Classical Mechanics and Electromagnetism Topics include: TBA

Exam 2: Quantum Mechanics, Statistical Mechanics and Thermodynamics Topics include: TBA

Both exams are offered twice each year (July and October).

Oral Candidacy Exam: The Oral Candidacy Exam is primarily a test of the candidate's suitability for research in his or her chosen field. Students should consult with the executive officer to assemble their oral candidacy committee. The chair of the committee should be someone other than the research adviser.

The candidacy committee will examine the student's knowledge of his or her chosen field and will consider the appropriateness and scope of the proposed thesis research during the oral candidacy exam. This exam represents the formal commitment

[11] http://web.mit.edu/physics/current/graduate/doctoral.html#exam

[12] https://physics.stanford.edu/academics/graduate-students/graduate-resources/qualifying-exam

of both student and adviser to a research program."[13]

Harvard: "Each student is also expected to pass an oral examination given by the student's faculty committee, ideally by the end of the second year, and certainly by the end of the third year. The purpose of the examination is two-fold: The examination aids in estimating the candidate's potential for performing research at a level required for the doctoral thesis, and also serves as a diagnostic tool for determining whether the candidate requires changes to the program of research and study.

For the examination, each student is asked to select, prepare, and discuss in depth a topic in physics, and to answer questions from the faculty committee both about that topic specifically and more broadly about the student's larger subfield. Originality is welcomed but not required.

The student selects the topic—preferably but not necessarily related to the proposed field of thesis research—and then submits a title and abstract together with a list of completed course requirements (described above under Program of Study) and a decision as to whether the prospective doctoral research will be experimental or theoretical. The student then confers in detail with the committee chair about the topic to be discussed and concrete expectations for the examination. The committee chair provides approval of the topic, and the overall composition of the examination committee must be approved by the Director of Graduate Studies. To ensure adequate preparation, this conference should take place at the earliest possible date, typically one to two months before the examination.

Oral examinations are evaluated on the knowledge and understanding students demonstrate about their chosen topic as well as about their general subfield. Students are also judged on the clarity and organization of their expositions. The examining committee may take into account other information about the candidate's performance as a graduate student."[14]

Princeton: The general examination has several components: the graduate preliminary exam and an oral exam with two parts. These tests are described below.

"All first-year physics graduate students are strongly encouraged to take the preliminary exam in January of their first year. The exam is also given in May, if needed.

The preliminary exam consists of four sections: mechanics; electricity and magnetism (EM); quantum mechanics; and thermodynamics and statistical mechanics (TSM). Each student must complete two of the three problems given in each section. The exam is given on two consecutive mornings, with mechanics and E&M on the first day, and quantum and TSM on the second day.

No calculators or other electronic devices or other assistance may be used during the exam. The solution to each problem is to be written in a separate exam booklet, so each student turns in four exam booklets at the end of each day's 3-hour exam session. The faculty grade the exam booklets and then meet to determine which students have passed the exam."[15]

"The experimental Presentation: The second section of the general examination is the experimental project, which consists of a report and oral presentation on an experiment that the student has either performed or assisted others in performing at Princeton. First year students should plan to spend three to four months on their project and they should begin by May of their first year. If you plan to work on it full time it should take about six weeks. The length and format of the write-up is flexible, but typically comparable to a report in a letter-type journal. It is advisable that the level be aimed at physicists who are not expert in the field. A written report is due to the advisor of your experimental project and the Graduate Administrator by the end of October of your second year. You will be given one grade for your write up by your advisor and one grade for your presentation from the Committee. Please plan your presentation to be no more than 15 minutes, since the main purpose is for the Committee to ask questions. The Committee will have received the written report prior to the oral presentation. Your presentation will be in front of a Committee of two professors that is put together by the Graduate Administrator. Questions about anything in your report are fair game as are reasonable questions about the equipment on which your report is based. You should be prepared to discuss the sources of systematic and statistical error as well. For example, if you did a report on the Sloan Digital Sky Survey you should know how the observations are made but not necessarily how the CCDs are placed in the focal plane. Remember, this is an experimental oral given by experimentalists! Dates for the experimental oral presentation are at this link. The Graduate Administrator will send out a sign up schedule for students to select a 30 minute time slot for their presentation.

Advanced project/pre-thesis: This is a research project in the student's area of interest, to be done under the supervision of a faculty advisor. The final product is a written report and an oral defense in the presence of a pre-thesis committee. One should have a prepared write-up no more than 20 pages and your talk should be absolutely no longer than 30 minutes. The format of the write-up that you submit to the department is flexible. You will get frequent questions. In this oral especially, we are looking for a depth of understanding that is indicative of independent research. This is not about reporting science but

[13] `https://www.pma.caltech.edu/research-and-academics/physics/physics-graduate-studies/requirements-for-a-doctorate-in-physics`

[14] `https://gsas.harvard.edu/degree-requirements/departmental-requirements/physics`

[15] `https://phy.princeton.edu/graduate-program/degree-requirements/graduate-preliminary-exams`

about intellectual engagement. You should know far more than you are able to present and that should come across in the presentation. You will provide your advisor and the Graduate Administrator with a final draft of your write-up three days before you present. It is your responsibility to schedule and choose your Committee of three professors. Your advisor will be one of your committee members. For the other two, they can be in your field but one of the two should be outside your research view. For example, you can have three theorists but one theorist needs to be outside your research view. If your advisor is in another department then one of the committee members needs to be a faculty member from the physics department. You are encouraged to think of pre-thesis committee members who will also serve on your thesis committee. Once you have a date and time, please contact the Graduate Administrator to reserve a room for you. The Committee will give one grade for your presentation. The deadline to complete your pre-thesis oral defense is before the start of winter break during your third year. There is wide agreement that these orals are fun: they give the faculty a chance to see what's happening in other fields. Come tell us what you've been thinking about!"[16]

Berkeley: Berkeley has a written "preliminary exam" and an oral "qualifying exam", both of which are described below.

"The preliminary examination is designed to ensure that students command a broad spectrum of undergraduate physics prior to their engaging in graduate research. The preliminary exam is a written exam composed of four sections, grouped by general subject areas of undergraduate physics. All four sections of the preliminary examination are offered at the beginning of both Fall and Spring semesters. A student who has passed all four sections of the exam will have passed the preliminary examination. The Department expects students to pass the examination within the first three semesters of graduate study (see further notes on this below).

The preliminary exam is intended as one tool for helping the Department evaluate that students are making adequate progress towards their PhD. The determination of a student's academic standing in the Department will be based on a student's entire record, including performance on the prelim exam, undergraduate coursework, graduate coursework, and research performance where appropriate. Consequently, a student would not be asked to leave the Department based solely on performance on the written preliminary exam.

The written exam has four sections, covering (1) classical mechanics, (2) electromagnetism and optics, and special relativity, (3) thermodynamics and statistical physics, and (4) quantum mechanics. Note that these divisions do not preclude the possibility of questions on one section that draw from subject matter emphasized in a different section. (For example, a question that touches on thermodynamics in the quantum mechanics section.) A student who passes any section of the written exam need not take that section again. Each section lasts three hours and covers traditional, textbook style problems, as well as more comprehensive questions that specifically test physical and numerical insight (e.g. order-of-magnitude estimates including physical constants, analyzing physical situations by application of general principles instead of complex calculations, etc.). A student's individual performance on each section of the exam, and not ranking relative to other students, will determine whether that student has passed or failed the section. In other words, there is no predetermined percentage of students to pass/fail the exam."[17]

"Within 2-3 semesters of beginning research, the Department expects students to take the University's Oral Qualifying Examination covering his or her research field and related areas. This exam is required for advancement to PhD candidacy, and signifies that the student is prepared and qualified to undertake research, not that the student has already completed a significant body of work towards the PhD. It is therefore expected to occur for most students in the 3rd year, and no later than the 4th year. A student is considered to have begun research when they first register for Physics 299 or fill out the department advising form showing that a research advisor has accepted the student for PhD work, at which time the research advisor becomes responsible for guidance and mentoring of the student. The examination is administered by a four-member committee (consisting of three Physics Department and one outside faculty member, including the research advisor) approved by the Graduate Division on behalf of the Graduate Council, and may be repeated once at the recommendation of the examining committee. The Department expects that all committees include at least one theorist and one experimentalist. For students with advisors from outside the department or who are not members of the Academic Senate (e.g., with appointments at LBNL or SSL), permission for a five-member committee may be requested from Grad Division to allow both the non-faculty and faculty advisor to be on the committee; in this case, approval of the proposed research by the Head Graduate Advisor and the Chair of the Department must also be obtained before the student takes their qualifying exam.

Rules and requirements associated with the Qualifying Exam are set by the Graduate Division on behalf of the Graduate Council. The committee membership and the conduct of the exam are therefore subject to Graduate Division approval. The exam is oral and lasts 2-3 hours. The Graduate Division specifies that the purpose of the Qualifying Exam is "to ascertain the breadth of the student's comprehension of fundamental facts and principles that apply to at least three subjects areas related to the major field of study and whether the student has the ability to think incisively and critically about the theoretical and the

[16] https://phy.princeton.edu/graduate-program/degree-requirements/orals-guideline
[17] https://physics.berkeley.edu/sites/default/files/_/prelim_policy.pdf

practical aspects of these areas." Grad Division also states that this oral qualifying exam serves a significant additional function. "Not only teaching, but the formal interaction with one's students and colleagues at colloquia, annual meetings of professional societies and the like, often require the ability to synthesize rapidly, organize clearly, and argue cogently in an oral setting.... It is consequently necessary for the University to ensure that a proper examination is given incorporating [these skills]."

The Qualifying Exam requires that the student, in consultation with his or her advisor, identify three topics which in the Physics Department are expected to be a proposed Thesis Topic, an Area of Research, and a General Area of Research. The General Area of Research is taken to be the sub-field within physics (e.g. astrophysics, biophysics, particle physics, condensed matter physics); the Area of Research to be a still broad but more narrowly defined field within the sub-field (e.g. magnetism, or QCD). For fields where these choices are not obvious, the student should suggest appropriately broad topics contiguous to their Thesis Topic. The choice of topics is subject to the approval of the Physics Department Head Graduate Adviser, per Graduate Council Requirements. Qualifying Exams in the Physics Department begin with a presentation from the student that is expected to last approximately, but no more than, 45 minutes, during and after which questions related to the presentation are typically asked. The presentation should focus on the student's research goals and necessary background material, including the proposed Thesis Topic and the Area of Research that encompasses the thesis topic, as well as a proposed schedule for finishing the PhD and goals/milestones in that schedule. After this presentation, following a short break if desired, members of the committee will further question the student both about the presentation itself and about the broader subject areas included in the General Area of Research, testing the student's "ability to think incisively and critically about the theoretical and the practical aspects of these areas". The Department expects these questions to be related to the student's research field, but to be broad in nature rather than narrowly related to the thesis itself. Ability to give a coherent and organized presentation and to answer questions on the three topics in an oral setting is also required for passing this exam. Note that adjustments may be made on the basis of campus policies for cases in which an otherwise able individual is prevented from meeting an oral requirement by a physical disability."[18]

Cornell: "As a graduate student you are expected to pass three examinations on the way to earning a Ph.D. These exams will be given by the members of your Special Committee. The exams will be individualized and reflect the particular emphasis and direction of your program.

The first is a qualifying examination, an oral examination that serves as a check on your progress and as a diagnostic of possible weaknesses that need attention. It is administered by your temporary Special Committee, during your third semester of study. You may have heard that at some schools the qualifying examination is used to pare down class size, to weed out students. This is never the case at Cornell. Each year, the physics department admits the number of graduate students that it anticipates being able to support throughout the length of their stay in the doctoral program. When you come to Cornell, you are secure in the knowledge that the department and your professors have made a valuable investment in your training. The faculty and staff are committed to helping you succeed.

The second examination is the Admission to Candidacy Examination (ACE), a comprehensive exam that gauges your knowledge of the field and readiness for independent research. This, too, is an oral examination, but it is administered by the members of your permanent Special Committee. Normally the 'A' exam, as it is called, is preceded by one or more written assignments. After passing this exam, usually sometime in your third year, you begin research in earnest.

Your third and final exam is the defense of your thesis. It is an oral exam that you take after you complete your Ph.D. thesis research and present it to the members of your committee. The exam covers your thesis and related matters."[19]

Chicago: "A committee of faculty members and the department's Executive Officer, the Candidacy Committee, are responsible for making up the GDE. It is generally administered two weeks prior to the beginning of the autumn quarter. The problems on the exam will be of the type and level expected on assignments and exams in the core graduate courses.

Entering graduate students are encouraged, but not strictly required, to take this examination. Taking the exam will help us better identify areas of strength and weakness, and allow students to place out of courses in subjects where they have sufficient knowledge. The exam will take place over four (4) days, four hours per day, with each day focused on one of the four subjects: classical mechanics, electricity and magnetism, quantum mechanics, and statistical mechanics.

While students are encouraged to attempt the examination in all four areas, they are free to choose only certain areas if it seems appropriate. Based on the results of the GDE, the Candidacy Committee will make one of the following determinations:

- The student has sufficient mastery in all subjects and is immediately advanced to Ph.D. candidacy

- The student has sufficient mastery in some, but not all, specified areas. The student will advance to candidacy after satisfactory performance in graduate courses to be specified by the committee.

- The student has not displayed sufficient mastery in any subject and must take the full slate of core graduate courses to achieve candidacy.

[18] https://physics.berkeley.edu/sites/default/files/_/qualifying_exam_infosheet.pdf

[19] https://physics.cornell.edu/course-of-study#required-exams

To prepare for the exam, we recommend that students review the highest level of coursework done in each subject of the core graduate courses."[20]

UIUC: "The Department of Physics requires all Ph.D. candidates to pass a qualifying examination. Its purpose is to ensure that a student has sufficient general knowledge in physics to proceed successfully toward the Ph.D. degree.

The qualifying examination is a written examination administered in two evening sessions. Each session contains a problem on classical mechanics (including relativity), electricity and magnetism, quantum mechanics, and thermodynamics (statistical mechanics). The exam tests competence in material that will have been covered in a solid undergraduate degree course in physics, but with the depth of understanding and technical facility expected after one year's enrollment in a graduate program. Accordingly, the level is sometimes said to be intermediate between undergraduate and graduate. The material covered is as follows:

Classical mechanics at the intermediate level (Physics 326), plus the special theory of relativity. Typical texts are Marion, Symon, Becker, and Fowles.

Electricity and magnetism at the intermediate level (Physics 436), including boundary value problems. Typical texts are Lorrain, Corson and Lorrain, Reitz, Milford and Christy, and Nayfeh and Brussel, with mathematical competence expected at the level of Chapters 1 through 7 of Jackson, and the electromagnetism parts of Wyld. (Cables and waveguides may be covered on the exam, although not at the level of Chapter 8 in Jackson.)

Statistical physics at the intermediate level (Physics 427), including the use of the Boltzmann, Gibbs, Fermi-Dirac, and Bose-Einstein distributions, classical and ideal gases, and black-body radiation. Typical texts are Chapters 1 through 14 of Kittel and Kroemer and Chapters 1 through 13 of Reif. These ranges of chapters are suggested as a study guide; other topics may be covered on the exam, as shown in the example problems.

Quantum mechanics at the intermediate level (Physics 486,487) and the beginning graduate level (Physics 580). Typical graduate texts are Dicke and Witte, Gasiorowicz, Park, Merzbacher, Baym, Landau and Lifshitz, Sakurai, and Schiff. Typical undergraduate texts are Eisberg, Park, and Cassels.

The examination is constructed to test your knowledge of the fundamental principles in each subject, applied to situations of physical interest. Elaborate formal questions are avoided. In particular, the portion of the examination dealing with quantum mechanics covers simple applications of Schroedinger wave mechanics to both bound-state and scattering problems, few-level systems, the Pauli theory of electron spin, and perturbation theory."[21]

Columbia: Note: Columbia has dropped its written qualifying exam as of January, 2021. This is the latest description on the website, which is now clearly out-of-date.

"The qualifying examination is taken by all students without exception, after no more than one term of residence. The examination begins with a written test, given in three parts in January – Part I covers Classical Physics, Part II covers Modern Physics and Part III covers General Physics including contemporary research and order of magnitude estimate. Each part consists of two sections. The written test is followed after approximately one week with an oral interview in which each student meets with three faculty members to go over the questions done on the written exams and to discuss research plans.

The material covered in the Physics Qualifying Examination is at the level of advanced undergraduate courses. It is intended that students will use their first semester in the program to review their overall knowledge of undergraduate physics and to fill in any gaps in their knowledge. The Qualifying Examination is intended as a diagnostic tool to help the faculty and the students know where there may be preparation gaps and allow these to be addressed before moving on to research. The Department relies on filtering that is done pre-admission by the Graduate Admissions Committee. Our experience is that the admissions process successfully identifies students with appropriate preparation so that the Qualifying Examination can be relied on as a fine-tuning diagnostic tool NOT a filter.

Following the oral exams, the faculty meets to consider for each student the results of the qualifying examination, the student's academic record to date and other available information. These criteria determine whether to permit a student to continue work toward the doctorate. Each student will then be placed in a category:

Pass: qualified to continue in doctoral program

Conditional Pass: decision withheld pending completion of specific course work

Retake Exam: must repeat the examination again when it is next given

Fail: cannot repeat the examination and must terminate

The results of the meeting are made available to the students shortly after the meeting by the Physics Director of Graduate Studies. Generally about 80% of the students pass the exam on the first try.

[20] https://physics.uchicago.edu/academics/graduate-programs/enrolled-student-resources/graduate-program-policies/

[21] https://physics.illinois.edu/academics/graduates/qualifying-examination

For students that do not pass on their first try, they are automatically allowed to take the exam the following year. Based on the results of the qualifying exam, in some cases students may be asked to either: (a) retake specific portions of the written exam, (b) retake the entire exam or (c) take advanced undergraduate courses in areas where the faculty have found weaknesses in preparation.

Generally, if a student fails to pass the exam on a second try, they will not be allowed to continue on to a PhD. They will be allowed to complete the spring semester, giving them the opportunity to consider their future options. In exceptional cases a student may be allowed to take the exam for a third time."[22]

Santa Barbara: "Students should be able to discuss the key questions that need to be addressed in their field and propose a possible line of research. To ensure that the student and the committee agree on what constitutes an acceptably broad definition of field, the student will submit a brief synopsis (see Synopsis Form) of his/her presentation at the time the exam is scheduled. The synopsis must be approved by both the chair of the committee and the wiseperson assigned to the exam.

Students will be evaluated on:

- whether the presentation addresses the underlying physics issues of the field and shows a reasonable understanding of the important problems;
- whether the student is able to respond adequately to questions from the committee.
- whether the student is progressing at an appropriate rate toward completion of the Ph.D.

Students must do well in all areas in order to pass."[23]

Michigan: "The student must pass a written Qualifying Examination based on material covered in standard advanced undergraduate physics courses. This requirement must be satisfied before the beginning of the third year. The exam includes questions on Mechanics, Electricity and Magnetism, Thermodynamics, Statistical Mechanics, and Quantum Mechanics at the level of advanced undergraduate material. Please note that the format of the qualifying exam was changed in 2018 and that older exams have a different format."[24]

Colorado-Boulder: Students are required to pass Comps I, II, and III. Comps I is met by passing 5 of the six required core courses with a B- or better. Comps II and III are described below.

"Comps II: Candidates are expected to take the Comps II examination within one year of completing Comps I and no later than their sixth enrolled semester. Comps II consists of the preparation of a formal paper that summarizes a broad research topic. The student then delivers an oral presentation about the content of the research paper, and undergoes an oral examination on the research topic as well as his/her general knowledge of physics. For more information, please review the Comprehensive Exam Process Guide for Students. Comps II research topic proposals should be submitted to the comprehensive exam committee chair. Students can obtain assistance with writing the paper by contacting Donald Wilkerson and by taking his Advanced Writing class (PHYS 7820), offered in the spring.

Comps III: Comps III is also known as Admission to Candidacy and serves two purposes. First is to demonstrate your knowledge of the field and your work. Second is to ensure that you have a plan in place to graduate. The exam is formalized as a thesis proposal, which should include information about your past work and what must be done in order for you to complete your thesis, including a timeline with milestones. This proposal can be a written document and/or presentation slides to be presented in a Comps III meeting (attended by a quorum of the Comps III committee) as decided in consultation between the student, advisor, and committee.

Comps III must be taken by the end of your 4th year. If you are unable to make that deadline, then you must submit a request for an extension to the Associate Chair of Graduate Studies, signed by you and your research advisor. If granted, an extension will be for one semester. Passing Comps III requires affirmative votes by a majority of the committee and any student who fails is allowed to retake it once after a time determined by the committee.

For Comps III, each student should follow the guidelines below to choose a five-member thesis committee, although only three (including the research advisor and titular advisor (if applicable)) are required to attend the Comps III exam. Please note: all five committee members must sign the exam form. Students should meet with their entire committee at least once a year. Then, when the student is ready to defend, four of these members will serve on the defense committee along with an outside member. All committee members must be on the graduate faculty. However, a researcher does not need to be a faculty member to have a graduate faculty appointment. Please see the Graduate Program Assistant for a current list of graduate faculty members."[25]

[22] https://physics.columbia.edu/content/phd-physics

[23] https://www.physics.ucsb.edu/education/graduate/candidacy

[24] https://lsa.umich.edu/physics/graduate-students/program-details.html

[25] https://www.colorado.edu/physics/academics/graduate-students/graduate-program-requirements-phd/comprehensive-exam-information

Maryland: There is a qualifying exam, preliminary oral research presentation, and the requirement for the submission of a scholarly paper.

"The Qualifying Exam consists of two parts: Classical Physics and Quantum Physics.

First-year students are welcome to take a "free try" during January of their first year. (Especially well-prepared students can request permission to take their free try in August when they first arrive.) This will not count toward the three exam limit.

A year after matriculation, students must take the "first try" of the exam, and take their second and third tries in the subsequent semesters. If the student cannot pass both parts of the Qualifying Exam after the Fall of their third year, they can appeal the Qualifying Committee to have an Oral Examination."[26]

"The purpose of the scholarly paper is for the student to demonstrate an understanding of their subfield sufficient for Ph.D. level research and also to demonstrate a level of competence in scientific writing. Accordingly it should be written by the student without coauthors. The scholarly paper can, but need not, contain a description of a completed original research project by the student. Alternatively it may summarize the state of the art of a subfield, describe a proposed future research project by the student or give a progress report on a partially completed research project. The scholarly paper can describe the results of research completed by the student with collaborators including their research advisor; in such cases, the scholarly paper will differ from the version submitted for publication since the published will have coauthors. However, the initial draft of a paper or a portion of such a paper can serve as part or all of the scholarly paper provided it is written solely by the student."[27]

Penn: "An Oral Candidacy Exam must be taken within 18 months of the successful completion of the four required courses in requirement 1. Before this exam can be scheduled, the student's advisor and the graduate chair must approve a short written statement describing the student's research topic.

The exam, which need not be public, is administered by a three-person committee. Typically, the thesis advisor is one of the committee members, with the others drawn from among the members of the Physics Graduate Group.

The oral part of the exam will include a presentation by the student followed by a question and answer session on the student's general field of study by the three-person committee.

Students who have not arranged for this exam by the 18-month deadline will not be allowed to register for the following term."[28]

Johns Hopkins: "This oral exam is given in the beginning of the second year (typically in the 3rd full week of September, although minor variations in schedule are possible in response to student, faculty and University schedules). The purpose of the exam is to review the student's progress through the pre-thesis research program conducted during the fall, spring, and summer of the first year. It also assists in training students to give formal presentations of scientific research, even at preliminary stages. There is no special report required in advance of the test. The reporting requirement is that a research report needs to be in place for each of the three periods of conducted research (fall, spring, and summer). It is understood that some of these research projects may be just past the level of a reading course, while others may be an actual research paper to be published. Students who have conducted multiple rotations in their first year should pick one topic to present in depth at the research exam.

At the research exam, students give a 15-minute presentation on the motivation, background, and progress made in their research. The first 10 minutes should be accessible and interesting to a broad audience, with the last 5 containing more specialized parts. The next 15 minutes are spent fielding questions from the committee. The questions typically focus on the research presented, but can reach beyond that to explore how well the student understands the context of their project and its physics background. The last 10 minutes are used for committee discussion. The committees consist of three faculty members from all areas of physics, with special care given to avoid using a student's research advisor. Therefore, students should avoid excessive technical jargon and abbreviations. After the exam, the student is provided with oral and written feedback from the research exam committee and the academic advisor. The outcome of the exam can be a Pass, a Conditional Pass, or a Fail. In the cases of a Conditional Pass or a Fail, the research exam committee and the graduate program committee will require remedial measures specific to each individual case. "[29]

UCLA: "The written comprehensive examination consists of two four-hour sections given on consecutive days, and its scope is defined by the graduate physics material in the six core courses (Physics 210A, 210B, 215A, 220, 221A, and 221B).

The written comprehensive examination is offered once a year, in the week before the beginning of classes in Fall Quarter. Students entering the graduate program in Fall Quarter are expected to take the written comprehensive examination before their

[26] https://umdphysics.umd.edu/academics/graduate/grad-qualifier.html
[27] https://umdphysics.umd.edu/academics/graduate/grad-requirements.html
[28] https://live-sas-physics.pantheon.sas.upenn.edu/graduate/degree-requirements
[29] https://physics-astronomy.jhu.edu/graduate/exam-guide/

fourth quarter of residence.

Students are required to pass the written comprehensive examination at the PhD level. This level is determined by the Comprehensive Examination Committee for each examination session. If students fail to pass the examination at the PhD level, they may take it a second time the next session it is given."[30]

UCSD: "In order to be advanced to candidacy, students must have met the departmental requirements and obtained a faculty research supervisor. At the time of application for advancement to candidacy, a doctoral committee responsible for the remainder of the student's graduate program is appointed by the dean of the Graduate Division. The committee conducts the PhD qualifying examination during which students must demonstrate the ability to engage in thesis research. This involves the presentation of a plan for the thesis research project. The committee may ask questions directly or indirectly related to the project and questions on general physics which it determines to be relevant. Upon successful completion of this examination, students are advanced to candidacy and are awarded the Candidate of Philosophy degree."[31]

UT-Austin: "The Oral Qualifying Examination. After satisfying the first two requirements above and within twenty-seven months of entering the program, the student must take the Oral Qualifying Examination. This examination consists of a public seminar presented before a committee of four Physics faculty members, one of whom is a member of the GSSC (see Section 2.1.3). It is followed by a private oral examination. The student chooses the topic of the seminar. The seminar need not present original work; he or she is expected only to demonstrate sufficient command of a specialty to begin original research in that area. The topic is usually that which will become your dissertation. As part of the examination, the student will generally be expected to indicate a problem whose solution would be a satisfactory dissertation. The questions are directed toward clarifying the presentation and helping the committee determine whether the student has a solid grasp of the basic material needed for research in his or her specialization. The student passes the examination by obtaining a positive vote from at least three of the four faculty members on the committee.

Preparation for the Oral Qualifying Examination and the "Pizza Seminar": Students are strongly encouraged to explore specialties in which they might pursue dissertation research. The "Pizza Seminar", held weekly in both the fall and spring semesters, is designed to assist students in choosing their research topics and supervisors. Faculty from all research groups (see Section 2.4) will talk about their research interests as well as discuss possible research topics suitable for students. The atmosphere is informal; pizza is served to all attendees. The pizza seminar is offered as a regular graduate course PHY 396T "Particle Physics: Introduction to Research". In addition, individual faculty list information on research interests on the web.

For most areas, certain advanced courses (see Section 3.3.3) are necessary to reach the level required for the qualifying examination. These courses and their prerequisites are also principal considerations in scheduling your courses during the first two years."[32]

[30] https://www.pa.ucla.edu/current-graduate-students.html

[31] https://www.ucsd.edu/catalog/curric/PHYS-gr.html

[32] https://ph.utexas.edu/current-graduate-students/degree-information#doctoral-degree

A.4 Qualifying Exam Descriptions: Yale Physical Sciences and Mathematics

Applied Math: The qualifying event is described as follows: ”Pass a qualifying examination on their general applied mathematical knowledge (in algebra, analysis, probability and statistics) by the end of their second year;”[33]

Applied Physics: ”Admission to candidacy indicates to all involved that the faculty believes that the student is prepared to do original and independent research. To reach this stage the Research Committee will administer an “Area Examination.” The purpose of this Area Examination is to ensure that the student has achieved both the breadth and depth of knowledge appropriate to a Yale Ph.D.

During the third academic year, and no later than October 5th, the Area Examination must be passed and a written prospectus submitted. At least 7 days prior to the exam date the student will have circulated a draft of the dissertation prospectus to his/her Research Committee and will have turned in the Event Scheduling Form to the Graduate Registrar. The examination will be announced publicly by the Graduate Registrar’s Office. One part of the Area Examination will consist of a summary by the student of his/her research activity and plans. At the discretion of the research advisor, this part may be open to all who wish to attend and questions may be allowed by any members of the audience and of the committee. The second part is restricted to questioning of the student (either oral or written) by the committee members or any other member of the faculty, in closed session. Area Examinations should be scheduled during the academic year, so that interested faculty and students can attend. Students will be notified promptly of the results of the exam.

Shortly after passing the Area Examination, and always in consultation with all Research Committee members, the student will revise, if necessary, his/her dissertation prospectus and submit it to the Graduate Registrar’s Office. These two requirements must be accomplished during term time so that the faculty assessment may be made in a timely fashion. At the latest, the student is admitted to candidacy in the Graduate School by the end of the third year.

A student will not be permitted to register for a fourth year unless the Admission to Candidacy has been granted.

A student who does not pass the Area Examination the first time will be given a second opportunity to take it. The second exam must be taken and the results reported to the DGS and Graduate Registrar’s Office by March 15.

If the student fails to pass the second time, he/she will be asked to leave the program.”[34]

Astronomy ”A written comprehensive examination, normally taken at the end of the fourth term of graduate work, tests the student’s familiarity with the entire field of astronomy and related branches of physics and mathematics. Particular attention will be paid to the student’s performance in the field in which the student plans to do research. An oral examination, held a few weeks after the written examination, is based on the student’s chosen field of research. Satisfactory performance in these examinations, an acceptable record in course and research work, and an approved dissertation prospectus are required for admission to candidacy for the Ph.D. degree.”[35]

Chemistry: ”The candidacy examination consists of both written and oral components. In each component students will be expected to demonstrate a thorough knowledge of the thesis area and related areas of chemistry, and to discuss competently the results that have been obtained and the future direction(s) of the project(s). In the written component students are expected to produce an independent proposal based on their Ph.D. project. The proposal should contain information about results obtained to date and planned future work.

The final written document is expected to be ten pages or less excluding references. The proposal should be provided to the committee at least one week before the oral examination.

The oral examination will consist of a two-hour examination based on the written proposal. For the oral examination, students should plan to arrive with 45 minutes worth of prepared material summarizing their written proposal (students often choose to use PowerPoint, Keynote, or similar presentation software), but should anticipate being interrupted with questions. In addition to testing the student’s knowledge of their Ph.D. project, the examination will emphasize fundamental chemistry and will probe the candidate’s comprehension of necessary background material, including topics that go beyond those specifically related to the thesis.”[36]

Computer Science: In their second year, ”A student continues taking courses, completing a total of ten courses by the end of the year. Two of these must be the CPSC 690 and CPSC 691 sequence, in which the student carries out a research project and writes a report on the results; these are known as the “690 project” and the “690 report.”

The end of the second year is the culmination of two years of study and research. The student must pass an area exam,

[33] https://applied.math.yale.edu/graduate-program/requirements
[34] https://appliedphysics.yale.edu/academics/graduate-studies
[35] http://catalog.yale.edu/gsas/degree-granting-departments-programs/astronomy/#programtext
[36] https://chem.yale.edu/sites/default/files/files/Grad/Grad\%20StudentHandbook\%202020-21.pdf

administered by the supervisory committee, in which he or she demonstrates breadth of knowledge in the research area of the 690 project. He must also finish the project itself and submit the report."[37]

Earth and Planetary Science: "Research Discourses: Students will carry out two modest independent research projects, which will culminate in two documents, referred to as the Discourses, that are to be submitted at the end of year 2. One Discourse – the Major Discourse – is expected to be more developed than the other and will take the form of a full research proposal (and will constitute the Dissertation Prospectus; see below) while the other Discourse – the Minor Discourse – can be written as a proposal or article. Both Discourses will be presented at the Qualifying Presentation (see below) with the Major Discourse comprising most of the talk.

To facilitate progress on the Discourses students will follow a schedule involving:

- Submission of brief Pre-proposals for each Discourse (submitted at the same time).

- Brief oral Preparatory Presentation on Major Discourse project plus progress-to-date on Minor Discourse Project (e.g., statement of the problem, fundamental background knowledge, context).

- Submission of the Major and Minor Discourses (at the same time).

Qualifying Presentation: Students will give a 40-minute formal oral presentation on the Discourses (about 30 min on the Major and 10 min on the Minor). During the subsequent extended questioning period they will defend both Discourses and be queried on supporting background knowledge. The Major Discourse eventually satisfies the Graduate School requirement of the Dissertation Prospectus. The Qualifying Presentation and the subsequent defense and extended question period satisfies the Graduate School requirement for the Qualifying Examination. The Minor Discourse would ideally become a publishable article, and if appropriate can become a chapter in the Dissertation (i.e. if it is related to the overall thesis topic)."[38]

Mathematics: "The purpose of the Qualifying Examinations is to help the student and the Department determine whether or not the student should continue in the Ph.D. program at Yale. These exams are meant to answer whether the student has mastered the basic material in the various fields to qualify as a member of the profession, and whether the student have the ability and preliminary knowledge to carry out a research.

Passing the Qualifying Exams is one of the basic Ph.D. requirements of the math department, and among the first that students encounter. Each one is a 4-hour written exam. The exams are offered at the end of each semester (though they may be offered at other times by request) and the student is required to pass, at high enough score, all three by the end of the second year. So normally there are 4 chances to take the exams. As there is no limit to the number of times one can take the exam, students are strongly encouraged to take the exam as soon as they feel that they can pass it.

The exams cover three topics: Algebra, Analysis and Algebraic Topology. The exams in Algebra and Analysis cover many subtopics that are learned in different courses (as can be seen below in the syllabi of the exams), whereas the exam in Algebraic Topology is given in the fall semester as the final exam of the related course, Math 544 (as such, the most updated syllabus of the exam is always the syllabus of the course, find it here and here). Thus, the students are encouraged to take the course in their first year and take the exam as the final exam. Past exams are available upon request from the Department Registrar. "[39]

[37] https://cpsc.yale.edu/sites/default/files/files/GRADHandbook\%2020-21.pdf
[38] https://earth.yale.edu/sites/default/files/files/Handbook_2017-2018.pdf
[39] https://math.yale.edu/grad-programs/syllabi-qualifying-examinations