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Essay

Nanocourses: A Short Course Format as an Educational Tool in a Biological Sciences Graduate Curriculum

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Traditional courses for graduate students in the biological sciences typically span a semester, are organized around the fundamental concepts of a single discipline, and are aimed at the needs of incoming students. Such courses demand significant time commitment from both faculty and course participants; thus, they are avoided by a subset of the academic science community. Course length and the high barrier to course development are inhibitory to the creation of new courses, especially in emerging areas of biology that may not merit a full-semester approach. Here, we describe the implementation of a new, graduate-level course format, created to allow for rapid development of courses, provide meaningful educational experiences for both junior and senior graduate students and other members of our community, and increase the breadth of faculty involvement in teaching. These courses are greatly abbreviated, and thus termed "nanocourses." Based on experience from the first three semesters, nanocourses seem to accomplish the initial goals that we set. Importantly, nanocourses engaged students, postdoctoral fellows, faculty, and others, thus providing a new mechanism to educate our community in response to rapid advances in biology. In our view, nanocourses are a useful tool that can supplement graduate-level curricula in varied ways.

INTRODUCTION

The current rapid pace of advancement in the biological sciences poses significant educational challenges in considering how to best train graduate students and help keep them up-to-date with new developments. Traditional educational approaches can only partially fulfill these needs, because they are typically geared toward students early in their training both in their content and structure. Although it was proposed in the mid-1990s that graduate education in the sciences should change to provide students with more opportunities to diversify their education, specific suggestions as to how to adapt the curriculum to accomplish this goal were not elaborated upon (Griffiths, 1995).

Although full-semester graduate courses are important for providing incoming students with a strong foundation in the biological sciences, these courses cannot possibly cover all of the material relevant to a particular field, and they are difficult to develop in response to student needs because of the time and effort required. In addition, full-semester courses are typically incompatible with the time constraints of upper-year graduate students, and others working in the university community. It has been suggested that educators must develop new approaches and formats to best educate busy students (Ebersole, 2004). To this end, faculty and staff in the Department of Cell Biology at Harvard Medical School (HMS) were interested in developing a new course format that could: allow rapid development of courses in response to community need, keep students and others current with changes in a particular field, supplement the curriculum with notable topics that do not fit neatly into traditional course content areas, and serve as a tool to help integrate areas of the curriculum. Importantly, we wanted to devise a mechanism that would appeal to upper-year graduate students, to provide them with additional opportunities to diversify their education, be mentored, and learn about topics and techniques relevant to their theses in a formalized way.

The format that was devised to best meet these needs was a short course format, previously described as a time-efficient way to facilitate learning (Kleinbaum, 1995). The con-

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densed nature of this format makes it well suited for: rapid course development; educating those with limited time to devote to formal classroom experiences; and enhancing the existing curriculum with integrative, supplemental, or novel course topics. These courses were designed to entail 5 h of total class time, incorporating both lectures and small-group discussion sections conducted by experts in a particular subject area. To reflect their abbreviated nature, these courses were nicknamed "nanocourses."

In addition to hypothesizing that the format of these courses would attract graduate students at various stages of their training, we believed that nanocourses would interest other members of our community, including postdoctoral fellows, clinicians, and potential course faculty. Creating a course format that was both available and suitable to all members of our community was anticipated to serve as an appealing new option for those who had not traditionally participated in course work. Concurrently, we hoped that we could expand participation in teaching to include faculty from departments outside of our graduate program who are not required to teach in our curriculum, thus increasing both the breadth and depth of educational opportunities available to students. We hoped that this would allow students to interact with additional faculty during their formal classroom education, thus enabling them to take better advantage of the extensive local scientific expertise.

Although there is an existing literature on short course formats, this literature primarily discusses workshops for continuing professional development rather than courses that are part of a graduate curriculum. As a component of the overall graduate curriculum at HMS, nanocourses are distinct from continuing education workshops in that they are developed with existing course content in mind, and they have been structured such that graduate students receive credit for their participation. In addition, nanocourses are separate from symposia, in that course lectures are intended to give an overview of a particular field, as opposed to specific details of lecturers' research progress.

Here, we describe the format of the nanocourse, assess the contribution of nanocourses to improving and expanding our educational program, and discuss some of the issues important to consider when making use of short courses as part of a graduate curriculum.

GENERAL FORMAT OF NANOCOURSES

Nanocourses were designed to consist of two separate class sessions totaling 5 h of class time. The first session is a series of 1-h lectures given by multiple faculty members. We aim to have at least three faculty members lecturing in each nanocourse, chosen based on their expertise in the course topic area. Although this first session is lecture based, an informal setting that promotes interruption and discussion is encouraged. Lecturers are asked to provide a comprehensive overview of the nanocourse topic, incorporating their unique knowledge and perspectives into their lectures. The goal of this session is to provide all participants with a broad view of the field, sufficient background to allow understanding of the major concepts, and a survey of the current questions being asked in that field. As a unique feature of this course format, attendance at this lecture session is open to any member of the scientific community, and it is broadly advertised as such.

The second session of each nanocourse provides students with an opportunity to have a focused discussion on the nanocourse topic, to facilitate and reinforce learning in the subject area. In contrast to the first session, this discussion session is limited to students taking the course for credit, ensuring that these students have adequate opportunity to interact with course faculty. All lecturers are asked to participate, providing a high faculty-to-student ratio (actual numbers for the first three semesters ranged from 2:1 to 1:8), and providing opportunities for students to observe scientific discussion among faculty members. Because one of our goals for this course format was to engage upper-level graduate students, we believed it essential to pitch the discussion at an appropriately advanced level to interest senior students and to challenge those junior students who chose to participate. Thus, the discussion sessions were structured to be integrative scientific discussions, more like the kinds of discussions that take place at focused scientific meetings. This approach is unique from other discussion sessions in our curriculum that tend to involve paper discussion or review of lecture material. Therefore, within our curriculum, nanocourses represent a unique curricular opportunity for students to think creatively and critically about specific research questions of interest with experts from that field.

Because nanocourses are abbreviated, it was critical to consider how to best facilitate student learning. As has been previously discussed elsewhere, in short course formats, the best learning occurs when students are asked to do more than merely "passively absorb" course material (Moon, 2004). As such, we provide participants with review articles and discussion questions 1 wk before the first session of each course. We also schedule courses such that there are several days between the lecture and discussion sessions, to allow adequate time for reflection, helping to reinforce concepts, and improve comprehension and retention (Kleinbaum, 1995; Moon, 2004). During this time, students develop a one-page written response to one of the discussion questions provided before the lecture session. Aside from the usual benefits of a writing assignment, namely: helping students to reflect and prepare before the discussion, allowing students to practice effective written communication of their ideas, and providing a way to meaningfully evaluate students, the writing assignment is also intended to help faculty direct the discussion toward areas of student interest. Tailoring courses to the interests of students is another approach that has been suggested to improve student learning in short courses (Birch, 1995). The combination of the writing assignment and participation in discussion are used to determine student performance in each nanocourse. Students are graded on a satisfactory/unsatisfactory basis.

INCORPORATING NANOCOURSES INTO THE CURRICULUM

To establish nanocourses as a course format, it was essential to determine how to award credit for student participation. The students in the Department of Cell Biology at HMS are part of the Biological and Biomedical Sciences (BBS) Ph.D. program, which is part of the Division of Medical Sciences

(DMS). The DMS curriculum is composed of semester-length courses and also half-semester courses (14–15 h of class time), nicknamed "quarter courses," that use literature-based discussions to teach specialized topic areas. Although students are only given credit for full-semester courses through the Harvard Graduate School of Arts and Sciences (GSAS) of which DMS is a part, DMS had previously developed a mechanism to grant students credit for taking two quarter courses.

The existence of a crediting system for quarter courses simplified the process of creating a crediting mechanism for the nanocourses. Because quarter courses are equivalent to 14–15 h of course time, and each full nanocourse entails 5 h of class time, it was determined that participation in three full nanocourses (including attending both the first and second session of the course and completing all relevant assignments) was equivalent to participation in one quarter course. Students can combine completion of three full nanocourses with the completion of one quarter course or three additional nanocourses to receive credit for one full-semester course. Students are not required to take all of the nanocourses required to receive credit in the same semester, but rather they can take courses over multiple semesters and still receive credit. This allows students the flexibility to take courses that suit their interests whenever they are offered. Students register for nanocourses and quarter courses through the DMS office, which keeps track of student course participation and submits registration for course credit to GSAS once a student has completed an appropriate number of courses for full-semester course credit. To provide students with suggestions as to which nanocourses are useful or interesting to take together, we group nanocourses into larger categories such as Experimental Tools for Biological Discovery, Cell Fate Decisions, or Neural Development and Regeneration. These categories are provided merely as suggestions as to what courses might complement each other. Students do not have to take nanocourses in any particular order or category to receive credit.

Before nanocourses were offered for the first time, the format was introduced to the community through an open town-hall style meeting and letters directed to faculty and students. Comments and ideas regarding the structure and content of these courses were solicited through both the meeting and letters. To facilitate the implementation and management of the nanocourse curriculum, a full-time instructor-level position was created. This position was intended to support the nanocourse curriculum through many important roles, including: identifying appropriate nanocourse topics to offer based on curricular needs and faculty and student interest; recruiting course faculty; coordinating faculty communication; monitoring student registration, participation, assessment, and credit; coordinating the courses to ensure continuity; and soliciting feedback from participants.

OUTCOMES FROM THE FIRST THREE SEMESTERS: DOES THE FORMAT MEET OUR GOALS?

A primary goal of establishing this new course format was to allow rapid development and implementation of new courses. We received approval for use of the nanocourse format in our curriculum from the program heads of the graduate programs at HMS in mid-October 2005. Beginning just 3 mo later in Spring semester 2006, we offered eight nanocourses (Table 1). Eight novel nanocourses were offered in the Fall semester (with one repeat offering), and nine nanocourses in Spring semester 2007 (with one repeat offering). Ten additional courses were offered in Fall 2007 (with one repeat offering). In all, this format has allowed us to develop 35 new courses in total in almost 2 yr since the program was initiated.

Another major goal of nanocourse development was to provide a curriculum that was appealing to graduate students, and especially upper-year students. In total, 219 unique students attended a nanocourse lecture session in the first three semesters, of which 174 were DMS students (other students came from Harvard graduate programs outside of DMS). There are 570 students in the graduate programs in DMS who are eligible to take nanocourses for credit; thus, approximately

Table 1. List of nanocourses offered

Spring 2006
1. Autophagy in Cell Death and Survival
2. B Cells: A Model for Studying Development
3. Fluorescence Live Cell Imaging
4. Formation and Regeneration of Skeletal Muscle
5. Live Cell Imaging of Membrane Trafficking
6. Neural Cell Identity
7. Neuron Migration and Axon Guidance
8. Neural Survival and Regeneration

Fall 2006
1. Analytical Approaches: Mass Spectrometry
2. Epithelia: Tissue Regeneration and Wound Healing
3. Fluorescence Live Cell Imaging
4. From Chemical Biology to Drug Design
5. Introduction to Protein Crystallography I
6. Molecular Visualization
7. Nitric Oxide and Nitric Oxide Synthases
8. RNAi Screening: From Design to Data Analysis
9. Single Molecule Biophysics

Spring 2007
1. Apoptotic and Non-Apoptotic Mechanisms of Cell Death
2. Development and Disease of Cardiac Muscle
3. Experimental Design for Biologists
4. Fetal Programming of Type 2 Diabetes and Metabolic Syndrome
5. Fluorescence Live Cell Imaging
6. Introduction to Protein Crystallography II
7. The Molecular Pathology of Cancer
8. Notch Signaling in Vascular Biology and Disease
9. Visualizing Molecular Processes with Maya
10. Wnt Signaling in Development and Disease

Fall 2007
1. Advanced Genome Searching and BLAST
2. EMT and Back Again: Cell Transitions in Organogenesis and Disease
3. Genetic Interaction: Principles, Measurement and Interpretation
4. Quantitative Light Microscopy Part I
5. Quantitative Light Microscopy, Part II
6. Reagents for Imaging Live and Fixed Specimens
7. Spinal Muscular Atrophy
8. Stem Cells and Development
9. Synthetic Biology: Cellular and Molecular Engineering
10. Using Immunohistochemistry Correctly and Effectively
11. Visualizing Molecular Processes with Maya

30% of all eligible students attended a nanocourse in the first three semesters they were offered. Of the 219 individual students who attended nanocourses in the first three semesters, 115 individual students participated in a full course (i.e., attended both the first and second sessions and completed the required assignment), 63 took more than one full nanocourse, and 44 took three or more full nanocourses. On average, approximately nine students registered to take each nanocourse for credit.

To assess whether this format attracted upper-year students to attend, we reviewed nanocourse registration data for students in their third year of graduate school or above. During the first three semesters they were offered, one-half of the students taking nanocourses for credit were in their third year or above (Figure 1). This differs significantly from the registration data for full-semester courses from the same three semesters, in which only 42 of 894 total students taking these courses for credit were in their third year or above (Figure 2A; note that these numbers represent the combined data from three semesters of the reported number of students taking each full-semester course, in which students taking more than one course are represented more than once). Although the fraction of upper-year students taking full nanocourses each semester has varied (Figure 2B), it has remained significantly above the fraction of upper-year students taking full-semester courses for credit (Figure 2A). Junior students also seem to find this format appealing, as the number of individual junior students attending nanocourses has increased each semester (Figure 2B). However, this does not seem to have negatively affected senior student participation in nanocourses, as approximately the same number of upper-year students have participated in nanocourses each semester. In addition, senior students are taking advantage of the opportunity to learn in the lecture sessions of nanocourses without participating in the full course to obtain credit, as 58% of students attending the nanocourse lecture session only were senior students. Based on these data, it seems that nanocourses are appealing to graduate students in general, and at least initially, they seem to provide a new educational niche for upper-year students.

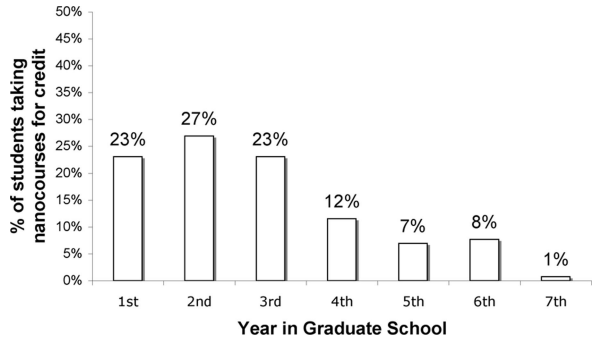

Figure 1. One-half of the students taking nanocourses for credit were in their third year of graduate school or above. During the first session of each nanocourse, attendees were asked to report their name, job title, year in graduate school if applicable, and their level of expertise with the topic on an attendance sheet. This graph includes the combined attendance data of all students taking nanocourses for credit during Spring 2006, Fall 2006, and Spring 2007 semesters, who reported their attendance and year of graduate training on the attendance sheet.

In addition to educating students, we hoped that nanocourses would be a useful and accessible tool to educate other members of our community. Based on the attendance data, we found that the lecture sessions of nanocourses did attract members of the biomedical community other than students. On average, each nanocourse attracted 46 attendees to the first session. About 42% of attendees to the nanocourse lecture sessions were postdocs (Figure 3). In addition to students and postdocs, faculty, physicians, research assistants, and medical fellows also attended (~20%). Therefore, other members of our community are taking advantage of the additional learning opportunities afforded by creating this nanocourse format. Together with the graduate student registration data, it seems that nanocourses can be rapidly developed in areas of interest to students and other members of the biomedical research community.

In addition to the demographic data collected at the first session of each nanocourse, we asked attendees to report their

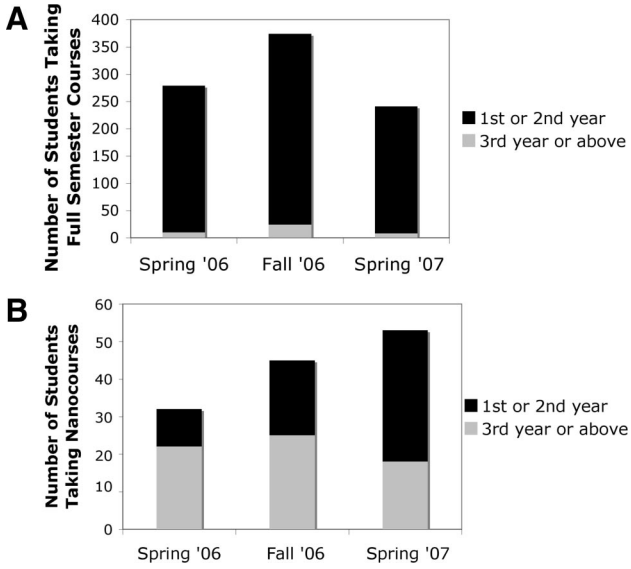

Figure 2. A greater fraction of the students taking full nanocourses were upper-year students compared with students taking full-semester courses for credit in the same three semesters. (A) Data are from all full-semester graduate-level courses offered by DMS during Spring 2006, Fall 2006, and Spring 2007 semesters (from DMS course registration records). Data were reported as the number of junior and senior students taking individual full-semester courses each semester. These numbers were combined, and are reported here as absolute numbers of students taking all full-semester courses each semester. Note that individual students who took more than one full-semester course are represented more than once, because we did not have access to the records indicating which specific students took these courses. Black bars represent the absolute number of students in their first and second year of graduate school taking full-semester courses for credit, while gray bars represent the absolute number of students in their third year or above. (B) This graph includes data from all nanocourses offered in the same semesters as were reported in A. Data are reported here as numbers of individual students taking nanocourses during each semester. Because we did have access to the records of individual students taking each of these courses, individual students are only represented once in each of the columns of this graph. Note that the scale of the two graphs is different.

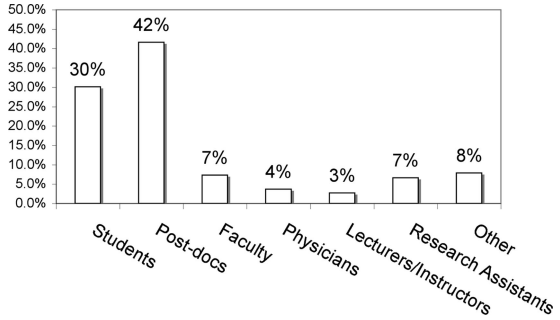

Figure 3. Nanocourses attract members of our community other than students. As described in Figure 1, during the first session of each nanocourse, attendees were asked to report demographic data on an attendance sheet. This graph includes the combined attendance data of all nanocourse attendees during Spring 2006, Fall 2006, and Spring 2007 semesters, who reported their attendance and job title on the attendance sheet. "Other" refers to a variety of job titles that were indicated on the survey forms.

level of expertise in the course topic. Surprisingly, 59% of students reported being beginners in a nanocourse subject area (data not shown). This result was unexpected, because we predicted that the highly specific nature of nanocourse topics might attract students who already had a vested interest and understanding in that area; however, this was not the case. In fact, when we surveyed students who had completed full nanocourses as to why they took these courses, many of the responding junior (69%) and senior students (66%) reported wanting to learn something new, unrelated to their thesis work or a potential postdoc topic (Table 2). This suggests that a number of students are eager to supplement their education with courses in novel subject areas. Student comments on surveys suggested that they felt the nanocourse format was appropriate for them to achieve this goal, emphasizing that the brevity of the format made it possible for them to learn about topics of interest not necessarily related to their thesis.

Even though many of the participating students reported being beginners in a nanocourse subject area, the majority of responding students (76%, Table 3) felt adequately prepared for all aspects of the course, suggesting that the courses were taught at an appropriate level. We interpreted this to mean that faculty lecturers presented lecture material at a level appropriate for students with prior graduate courses in the biomedical sciences who were otherwise novices in the subject matter and that posted review articles were likely sufficient to prepare these novices for course lectures. At the same time, the material was not too basic, as 86% of surveyed students became more interested in the nanocourse topic after participating in the course (Table 3). The unique style of the nanocourse may have contributed to this increase in student interest, as the majority of students (75%) indicated that the nanocourse material was presented in a way that was different from other courses they had taken (Table 3).

In considering other reasons why students chose to take nanocourses, popular choices included: the topic related to their thesis; the course covered a technique relevant to their thesis work; and the potential to interact with faculty mentors, in addition to the aforementioned reason that students wanted to learn something new (Table 2). In comparing the reasons junior and senior students take nanocourses, we observed that the distribution of responses were fairly similar, with marked differences occurring in only two categories: junior students were more likely to take courses that had the potential to help prepare them for their qualifying exam (65% of junior vs. 30% of senior students), and senior students were more likely to take courses to help them learn about a potential postdoc topic (19% of junior vs. 30% of senior students), which likely reflects differences in stages of graduate training. However, it is important to emphasize that, for the most part, junior and senior students reported nearly the same reasons for taking nanocourses. We also asked students to assess the single most important element they consider when choosing a nanocourse. Again, both junior and senior students responded very similarly, suggesting that both groups of students have largely the same goals when taking these courses. The most commonly reported element was the opportunity to learn about the current state of a specific discipline (69% of junior and 68% of senior students; Table 4). In addition, other selected elements included learning about topics related to their thesis project (6% of junior and 8% of senior students), learning about techniques related to their thesis (19% of junior and senior students), and interacting with faculty (6% of junior and 5% of senior students). None of the responding students selected interacting with fellow students, exploring potential postdoc fields, or receiving credit as the most important element in choosing a nanocourse. Based on these data, it seems both junior and senior students are similarly interested in nanocourses as continued opportunities to learn and interact with faculty.

Student perceptions of how well the courses met their goals were generally positive (Table 5), with all except one of the means falling above the middle score on a 5-point Likert scale, where a value of 1 was a positive response, and a value of 5 was a negative response. Responses from junior and senior students were fairly similar on most points; however, senior

Table 2. Why do students take nanocourses?

	Junior students	Senior students
They thought it would help in their thesis work	45%	57%
It covered a topic area relevant to their thesis	75%	82%
It covered a technique related to their thesis work	69%	73%
It could help them prepare for their qualifying exam	65%	30%
They wanted to learn more about a potential postdoc topic	19%	30%
They wanted to learn something new NOT related to their thesis or a potential postdoc	69%	66%
Because of the potential to interact with faculty mentors	81%	81%

Data were collected from surveys distributed to all students who took a nanocourse for credit during the Spring 2006, Fall 2006, and Spring 2007 semesters. 53 student surveys were returned. Students were allowed to choose more than one option with respect to why they took nanocourses. Students in their first or second year of training were considered junior students, whereas students in their third year of training or above were considered senior students.

Table 3. Student evaluations of nanocourses immediately following completion of a course

	Yes	No	Other	No response
Did the course enhance your interest in the field?	86%	3%	10%*	1%
Do you think the course presented material in a way that was unique to other courses you have taken?	75%	7%	15%**	3%
Did you feel adequately prepared for the lectures and discussion sections?	76%	11%	11%***	2%
Did the lecturers present a multidisciplinary viewpoint and approach to the study of the nanocourse topic?	72%	7%	8%***	13%

Data were collected from surveys distributed to all students who took nanocourses for credit during the Spring 2006, Fall 2006, and Spring 2007 semesters. Surveys were distributed immediately after completion of the discussion session. Students were asked to answer the above questions with respect to the specific nanocourse they had just completed. The first three questions were asked of all students who took nanocourses for credit in all three semesters (195 submitted surveys). The last question was added to the survey in Fall 2006 (145 submitted surveys).

*This category represents answers that did not fit as "Yes" or "No," such as "confirmed my interest," and "I was already interested."

**This category represents comments that discussion sections, but not lectures, were unique.

***This category represents answers such as "somewhat," "kind of," or "for the most part."

students tended to respond most positively about the extent to which nanocourses helped them to learn something new, whereas junior students tended to respond most positively about the extent to which nanocourses helped them learn something about their thesis topic. This may reflect changes in student motivations for learning content at different stages of their training. In evaluating student perceptions of how nanocourses compare with quarter courses and full-semester courses with respect to offering opportunities for intellectual maturation, the average score for responding students was toward the positive end of the Likert scale in both cases, suggesting that students perceive this format to be effective compared with pre-existing course formats. In both cases, senior students responded slightly more positively to these questions than junior students, which may be due to their lack of participation in these course formats at this stage of their training. Together, these data suggest that nanocourses are offering the students a novel and effective opportunity to meet their learning goals. Importantly, 100% of students who responded to these surveys indicated that we should continue to offer nanocourses.

One of the ways we hoped to use nanocourses was as a tool to integrate aspects of the curriculum, and teach course concepts in an interdisciplinary way. It has been suggested that graduate students must learn to approach science in an interdisciplinary, integrative manner if they are to be effective in their fields (Griffiths, 1995; Gaff, 2002; Pearce, 2002). So far, many of the nanocourses offered have been interdisciplinary in nature, although the manner in which they achieved this has varied. For example, the Formation and Regeneration of Skeletal Muscle nanocourse approached the topic from various perspectives, including discussion of the relevant cell biology, biochemistry, anatomy, and physiology important to understand this particular topic. Other courses used lecturers who use different experimental approaches or model systems to study similar scientific questions. One example is the Neural Cell Identity course, which included lecturers who worked in *Drosophila*, mouse, and in vitro systems. In addition to these approaches, on average, faculty members from two separate departments taught in each nanocourse. Having nanocourse faculty from different departments is a straightforward way to incorporate interdisciplinary perspectives into nanocourses. In response to these efforts, 72% of students responding to course surveys reported that they felt that lecturers presented a multidisciplinary viewpoint to the nanocourse (Table 3).

Finally, we hoped the nanocourse format would attract a broader range of faculty willing to participate in teaching in our graduate program. In addition to the 36 faculty members from within the BBS graduate program who taught in nanocourses, we recruited 31 lecturers from outside of the BBS program, for a total of 67 unique lecturers in the first three semesters, of which 63 were faculty (Table 6). These 63 faculty lecturers were drawn from 22 different departments within Harvard, and four departments from outside of the Harvard

Table 4. The single most important element students consider when choosing a nanocourse

	Junior students	Senior students
Interacting with faculty	6%	5%
Interacting with fellow students	0%	0%
Learning about the current state of a specific discipline	69%	68%
Exploring potential postdoc fields	0%	0%
Learning about topics related to your thesis project	6%	8%
Learning about techniques related to your thesis project	19%	19%
Receiving credit	0%	0%

Data were collected from surveys distributed to all students who took a nanocourse during the Spring 2006, Fall 2006, and Spring 2007 semesters. 53 student surveys were returned. Students were asked to consider the nanocourses they had taken, and to select the most important element considered when they chose to take a nanocourse. Students in their first or second year of training were considered junior students, whereas students in their third year of training or above were considered senior students.

Table 5. Student perceptions of the nanocourse format

	Junior students	Senior students
Number of nanocourses taken for credit	2.06 (1.09)	2.84 (1.60)
Rate the extent to which nanocourses helped you:		
Learn about a topic area related to your thesis work	1.92 (1.04)	2.07 (0.81)
Learn a technique related to your thesis work	2.18 (1.34)	1.92 (1.15)
Learn something new NOT related to your thesis or potential postdoc	2.17 (1.34)	1.83 (0.92)
Prepare for your qualifying exam	2.75 (1.42)	3.18 (1.64)
Improve your confidence in participating in scientific discussion	2.25 (1.44)	2.48 (1.42)
Interact with potential faculty mentors	2.23 (1.25)	2.37 (1.08)
How effective are nanocourses in offering opportunities for intellectual maturation as compared to quarter courses?	2.19 (1.28)	2 (0.96)
How effective are nanocourses in offering opportunities for intellectual maturation as compared to full-semester courses?	2.31 (1.31)	2.14 (1.12)

Data were collected from surveys distributed to all students who took a nanocourse during the Spring 2006, Fall 2006, and Spring 2007 semesters. Fifty-three student surveys were returned. Questions that asked students to rate or evaluate the format used a 5-point Likert scale, with a value of 1 representing "Helped a lot" or "Very Effective," and a value of 5 representing "Not at all." Values from responding students are reported here as means, with SDs in parentheses. Students in their first or second year of training were considered junior students, whereas students in their third year of training or above were considered senior students.

community. Of the 27 faculty lecturers from outside of the BBS program, 26% were faculty in DMS programs outside of BBS, 59% were Harvard faculty outside of the DMS graduate programs who are not required to teach DMS students, and 15% were non-Harvard faculty (visiting scholars). Therefore, we were successful in recruiting faculty from both within and outside our graduate program. Because some of these lecturers have never taught in other courses (Table 7), and are not required to teach within our graduate curriculum, students were afforded novel opportunities to learn from these faculty. However, the majority of lecturers who responded to our survey (87%) do teach in other courses, suggesting that nanocourse teaching can be incorporated into the schedules of faculty who already participate in other types of teaching. In the case where they were specialists in the subject area, we have also had students and postdocs (four total) lecture in nanocourses with faculty supervision. Thus, this format can provide an opportunity for students and postdocs to teach with direction and feedback from other course faculty.

The comments of faculty who have participated in nanocourses have been positive. Notably, 80% of responding lecturers said they would teach in a nanocourse again (Table 7). In informal conversations and on faculty surveys, faculty also mentioned that they valued the brevity of the format and that they appreciated the opportunity to interact with other faculty with similar expertise in the lectures and discussion sessions. In the faculty surveys, a percentage of the faculty indicated that students taking nanocourses were more interested (23%), or better prepared (27%) than students taking other courses that they teach. Together, these findings may be useful in encouraging additional faculty to participate in teaching these courses.

FUTURE DIRECTIONS

Based on the evaluations from students and faculty, we have initially met our goals of offering a course format that can attract and serve the needs of upper-year graduate students; educate members of our community who do not typically participate in course work, and serve as a tool to supplement and integrate our curriculum. However, we plan to continue to develop the nanocourse program based on participant feedback and identification of areas of weakness in our curriculum, to continue to hone the format and address our curricular needs.

One of the benefits of nanocourses is the ease with which they can be developed to supplement underrepresented areas in the curriculum. To identify curricular gaps, we actively: 1) survey nanocourse students about areas they feel are underrepresented in the full-semester courses; 2) review syllabi for semester-length and quarter courses, so that we can identify topics missing from the curriculum; and 3) survey faculty to ask whether they perceive any specific weakness in students' education. Our initial attempts at identifying curriculum gaps using these methods have yielded potential nanocourse topics including Two-Photon Microscopy, The Biology of Sensation, and Host–Pathogen Interactions. We have received several suggestions from graduate students for particular nanocourse topics they would like to see developed, and so far, we have developed three nanocourses as a result, including Advanced Genome Searching and BLAST (Fall 2007), Chromatin Dynamics (Spring 2008), and Mechanisms of microRNA Silencing (Spring 2008). The ease of using this format to promptly develop courses directly in response to student requests or interests is enabling students to be more active participants in their own graduate education experience. We hope to further encourage and respond to student input in nanocourse development.

Another area of interest for nanocourse development is the creation of clinically relevant graduate-level courses to provide meaningful opportunities for medical and graduate students to learn together. Despite the coexistence of these two student groups on the HMS campus, this type of interaction does not often occur. We believe the nanocourse format is amenable to this type of educational integration; therefore, we have begun to offer nanocourse topics of potential interest to both types of students. Specifically, we have offered nanocourses on topics related to disease (for specific topics, see Table 1) with lectures that cover basic biology as well as clinical issues. Although we have chosen topics that we felt would be of interest to medical students, and offer the courses at times that could fit with the schedules of at least some students, we have not had much success at attracting medical students to nanocourses. We therefore intend to develop additional ways to encourage medical student participation in these courses, to provide opportunities for meaningful scientific interaction between graduate

Table 6. Departments of nanocourse teaching faculty

Program affiliation	Faculty member's home department (institution)	Number of lecturers (unique)
Harvard faculty from the BBS graduate program	Biological Chemistry and Molecular Pharmacology (HMS)	8
	Cell Biology (HMS)	11
	Genetics (Brigham and Women's Hospital - BWH)	1
	Genetics (Children's Hospital - CH)	1
	Genetics (HMS)	6
	Medicine (BWH)	3
	Neurology (CH)	1
	Neurology (Beth Israel Deaconess Medical Center)	1
	Pathology (BWH)	1
	Pathology (Mass General Hospital - MGH)	2
	Pediatrics (CH)	1
Harvard faculty from DMS graduate programs other than BBS	Hematology/Oncology (CH)	1
	Medicine (BWH)	1
	Medicine (MGH)	1
	Molecular and Cellular Biology (Faculty of Arts and Sciences - FAS)	2
	Neurobiology (HMS)	1
	Opthalmology (Schepens Eye Institute)	1
Harvard faculty not part of DMS graduate programs	Ambulatory Care and Prevention	2
	Anesthesia (MGH)	2
	Biological Chemistry and Molecular Pharmacology (HMS)	2
	Cell Biology (HMS)	2
	Chemistry and Chemical Biology (FAS)	2
	Dermatology (BWH)	1
	Genetics (HMS)	1
	Medicine (BWH)	1
	Neurology (CH)	1
	Neurology (MGH)	1
	Radiology (MGH)	1
Non-Harvard faculty	Departments outside of the Harvard community	4
Non-faculty lecturers	N/A	4

and medical students on our campus. As a part of this, we plan to advertise more broadly to the hospitals and to discuss the course format and our approaches with faculty and staff responsible for the medical school curriculum.

In addition to developing additional new courses to supplement the curriculum, we also want to continue to evaluate and update the format. One possibility for improving the nanocourse program is to diversify the format of the second session. Although posing discussion questions has stimulated useful and interesting discussions distinct from other discussion sessions in the curriculum, it is possible that structuring these sessions in different ways may offer further opportunities for intellectual maturation, and for addressing student goals. For example, having students write miniproposals on an area of research relating to the nanocourse topic, and discussing these proposals with the nanocourse instructors on the second day of the course could provide opportunities for students to: think deeply about the topic, discuss techniques used to address basic questions in that area, and receive feedback on experimental design and proposal writing. We will continue to evaluate the effectiveness of different approaches to teaching the students in these interactive sessions on the second day of the course.

Table 7. Faculty perceptions of the nanocourse format

Do you teach in other courses besides nanocourses?	87% Yes	13% No		
Did you prepare a lecture specifically for the nanocourse or did you make minor adjustments to a previously used lecture?	57% New	33% Modified	0% Old	10% No response
Would you teach in a nanocourse again?	80% Yes	7% Maybe	0% No	13% No response
Compare the interest level of students in your nanocourse to those in other courses you teach.	23% Greater than	47% Same	3% Less than	27% Couldn't evaluate
Compare the participation of students in your nanocourse to those in other courses you teach.	27% Greater than	30% Same	27% Less than	17% Couldn't evaluate

Data were collected from surveys distributed to all faculty who taught nanocourses during the Spring 2006, Fall 2006, and Spring 2007 semesters. Teaching faculty were asked to assess the overall nanocourse format using the above questions. Thirty faculty surveys were returned in the first three semesters.

CONSIDERATIONS AND SPECIAL CHALLENGES OF IMPLEMENTING A NANOCOURSE SERIES

Nanocourses could be used as a tool by other universities to supplement curricula in biology and other fields, because of the proven benefits of the format: ease of course development; attractiveness to a variety of participants who may or may not traditionally take courses; and freedom to teach a course of need or interest to the community, which may not merit a full-semester approach. However, to implement this course format, there are some critical issues to consider to smoothly integrate nanocourses into an existing curriculum.

The most challenging aspect in the development of nanocourses was standardization. The ease of course development is certainly a benefit of the format, but it can also be a bane, in that rapid, uncontrolled course development can lead to a deterioration in the overall quality of the courses offered. Having an overseeing committee and an instructor dedicated to nanocourses has been fundamental to addressing this issue. The committee meets as needed to discuss the progress of the nanocourses and special issues that need to be addressed. The instructor is fully focused on the nanocourses and in addition to her role in working with the course directors to help them develop and run each course according to the guidelines established by the committee, she also assesses how to improve individual courses, evaluates the progress of the format as a whole, and identifies topic areas that are best integrated into the curriculum through courses of this nature. Assigning the task of overseeing the nanocourse program is highly recommended for the success of the program, which may or may not require hiring an additional instructor.

We are fortunate to have a large number of university and university-affiliated faculty on which to draw from for our nanocourses. However, in the case that a short course on a topic outside of the faculty expertise is desired, we considered the use of visiting scholars as lecturers. In fact, this approach has been used successfully in several nanocourses thus far. In two cases (Autophagy in Cell Death and Survival; Development, Disease and Regeneration of Cardiac Muscle), we held a short, lecture-based meeting before the visiting scholars' seminar, and then had students attend the seminar and finally participate in a discussion session with the seminar speaker and lecturers from the first meeting day. This alternative nanocourse approach provides students with opportunities to interact closely with scholars from outside institutions, providing possibilities for networking and meeting potential scientific and postdoctoral advisors. In general, use of outside speakers may expand the wealth of topics that could be covered in a nanocourse curriculum at any university.

We believe that nanocourses should primarily be used as a tool to supplement traditional courses in a graduate curriculum. Semester-long courses are critical for establishing a strong understanding of the fundamentals on which students can build a depth of knowledge. Nanocourses are intended to build on that fundamental knowledge by helping to integrate distinct scientific fields, provide information on specialized topics, and allow opportunities for exploration through high-level scientific discussion. Because nanocourse success relies on a students' understanding of fundamentals, we believe the nanocourse format, as described here, is an approach best used for educating graduate students.

CONCLUSIONS

The creation of nanocourses has provided our training program with a powerful, new tool to address some of the current educational challenges of preparing biology graduate students to excel in their future careers. Nanocourses have proved popular with students, postdocs, and faculty alike, and they have accomplished many of the goals we established in developing a new curriculum format. Despite the brevity of nanocourses, we believe they provide a high-impact training experience as long as high standards are maintained for faculty involvement, student preparation, and participation. Fundamentally, nanocourses are a tool that can be used to complement traditional graduate-level courses in different ways. We believe their advantages could make them amenable to use in other graduate programs in both the biological sciences and in other academic disciplines.

For more information and the most up-to-date schedule of nanocourses, please see our website at http://idb.med.harvard.edu/.

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