Undergraduate Students Conducting Research in the Life Sciences: Opportunities for Connected Learning

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Introduction

Over the past decade, a number of scholars have publicly criticized large research universities for failing to provide undergraduate students with the skills and abilities needed to succeed both in life and in the workforce. At the heart of this criticism is the concern that research institutions have de-emphasized teaching by increasing the size of undergraduate classes, expanding the role of teaching assistants, and structuring the faculty promotion process so that it provides greater rewards to those who conduct exceptional research at the expense of student learning (Boyer, 1990; Boyer Commission, 1998). Concerned, a number of institutions have examined their curriculum, looking for ways to improve the quality of the undergraduate experience. One strategy, taken at UCLA, is to use our strength as a research institution as the foundation of curricular reform; for example, by bringing research experience into science general education (Kerfeld, Levis, & Perry, 2001). We have developed a program (www.lsic.ucla.edu/ugri) in which large numbers of students (nearly 2,000 annually) participate in a research project in the context of their undergraduate coursework. The Undergraduate Genomics Research Initiative (UGRI), uses a common research goal, the sequencing of a microbial genome, to link several upper and lower division life sciences courses and science general education courses. In order to facilitate this multi-course collaboration, it was necessary to invent a new course based entirely on undergraduate research to serve as the hub of the UGRI. This paper presents findings from the assessment of this novel course, Life Sciences 187, *Principles and Practices of Genomic Research*.

Conceptual Framework

Institutions across the country are examining the undergraduate curriculum with an emphasis on academic and personal development. A number of professional associations and blue ribbon panels have advocated fundamental change in the design and delivery of undergraduate education, particularly in large universities (e.g., Boyer Commission on Educating Undergraduates in the Research University, 1998; National Research Council, 2003).

Most agree that the undergraduate curriculum is in special need of attention. A complete review of the recommendations is beyond the scope of this paper, but most reports agree on at least the following: (a) pedagogical methods that foster active learning, including opportunities for students to participate in inquiry-based education and research, offer numerous benefits; (b) barriers to interdisciplinary education should be removed; (c) courses and curricula should be designed to help students make connections among concepts, ideas and meanings; (d) institutions should strive to build community and instill in students a sense of belonging to the academic enterprise; (e) students need a stronger foundation in writing and other communication skills, including the use of new technologies; and (f) given the increasing significance of the life sciences, science education should be strengthened.

The Boyer Commission on Educating Undergraduates in the Research University (1998) and the National Research Council's Committee on Undergraduate Biology Education to Prepare Research Scientists for the 21st Century (2003) have identified developing the undergraduate research experience as a top priority in undergraduate education reform. Both panels suggested making research-based learning the standard.

Although undergraduate research is not a universal remedy for all problems, it is one way in which students can feel more connected to their educational experience (National Institute of Education, 1984). At a broad level, such connected learning programs have been associated with higher levels of satisfaction by both students *and* faculty (Hakim, 1998; Mabrouk & Peters, 2000; Manduca, 1997), as well as increased retention rates (Nagda, Gregerman, Jonides, von Hippel, & Lerner (1998). At a more specific level, research experience – especially laboratory experience – stimulates student interest and participation, cultivates the ability of students to think independently, and teaches students how to work cooperatively in groups (NRC, 2003). Project-based laboratories are also ideal settings for students to develop their scientific writing, speaking, and presentations skills (NRC, 2003), all of which contribute to their intellectual and social development.

Accordingly, UCLA, a large public research university enrolling about 24,000 undergraduates and 7,000 graduate students is in the process of transforming its undergraduate science education curriculum. As part of this process, we have developed the UGRI to bring research experience into the curriculum in the context of undergraduate classes. To realize such a collaborative program, it was necessary to create a hub course, Life Sciences 187. This unique course offers experience in inquiry, analysis, collaboration and communication through an innovative discovery-oriented experience based on the growing field of genomics.

Research Question:

Does conducting "hands-on" research in a laboratory promote active and connected learning in the life sciences?

Program Description

UCLA's innovative undergraduate curriculum is the ideal setting in which to emulate the collaboration among scientists, industry and society that is essential to today's science. Our goal is to unite the community of this university's undergraduates by making them part of a research team working together to share the goal of sequencing a microbial genome. The design of the UGRI is based on the belief that actual research experience is the best way to achieve all levels of practical and theoretical scientific literacy.

A microbial genome sequencing project involves several experimental steps. We have situated each among a variety of courses. They are:

1. Prepare a genomic library
2. Isolate DNA from the library
3. Prepare the DNA for sequencing
4. Sequence the DNA
5. Perform bioinformatic analysis of the DNA sequence
6. Build and curate the genome sequence database

The core course of the UGRI is LS 187, *Principles and Practices of Genomic Research*, where approximately 20 students are enrolled each quarter. This course is designed for students just entering upper division life sciences coursework. The student experience in this course is

modeled on the modern research laboratory. The students use a state-of-the art DNA sequencer and perform bioinformatic analyses of the data they obtain. Teamwork is essential-- for each student does one part of each day's experiment; some students are involved in expanding and maintaining the library (step 1), others prepare the instrumentation or work with the DNA samples (steps 3 and 4) or develop and manage the database (step 6). In this way they learn vital skills such as communication and collaboration--necessary to each day's successful experiment in sequencing.

Students also have the opportunity to develop mentorship skills. Students may elect to enroll in LS 187B and, subsequently, LS 187C. In each successive course the student takes on greater responsibility in terms of leadership and database curation. All students participate in a weekly lab meeting, in which their understanding of the theory behind the science they practice is deepened. We discuss lab issues-- troubleshooting the problems and conflicts that, as in any modern research laboratory, inevitably arise. We also review our progress and explore the implications of our genomic research.

Not only is the UGRI a model of the collaborative nature of modern genomic biology, but it also reflects the growing synergy between industry and academic research. UCLA has partnered with the LI-COR corporation, a leader in DNA sequencing technology, to examine the feasibility of bringing real research in genomics into the undergraduate curriculum.

The UGRI is unique for its emphasis on collaboration, teamwork and a dedicated goal of conducting actual research. It is unique as its central focus is not a "canned" exercise with a preordained outcome. Instead, students experience the excitement of real research while developing a sense of pride and accomplishment as they build toward a research goal, the sequencing of a microbial genome.

Methodology

The main strength of the UGRI assessment was the use of multiple methods, both qualitative and quantitative; the data were collected from multiple perspectives (i.e., from students and faculty). The primary methods in the assessment included student surveys, student focus groups, and faculty interviews conducted during the 2003-2004 and 2004-2005 academic years. High participation rates contributed to the strength of the assessment. For the 2003-2004 academic year, the assessment took place at the end of the Spring 2004 quarter only. However, for the 2004-2005 academic year the assessment took place at the end of each quarter (i.e., Fall 2004, Winter 2005, and Spring 2005 quarters).

The surveys administered to students in the LS 187 A, B, and C courses during the 2003-2004 academic year included questions about students' (1) demographic or background characteristics (e.g., gender, ethnicity), (2) major, (3) interaction and learning, (4) skill development, and (5) sense of community. The surveys administered to students in the LS 187 A, B, and C courses during the 2004-2005 academic year included some additional questions: (6) motivation for enrolling in the course, (7) future plans for research, and (8) general comments and suggestions for improvement. Appendix A contains a copy of the student paper survey. Parts 1, 3, and 4 were the additional questions added to the 2004-2005 instrument.

For the 2003-2004 academic year, other students who did not continue in the LS 187 course for the spring 2004 quarter were contacted either by email or phone requesting completion of the student survey (see Appendix A for a copy of the student email/phone survey). For the 2004-2005 academic year, because the assessment occurred at the end of each quarter, there was no need to contact students who did not continue in the LS 187 series for the entire academic year.

In order to gain a deeper understanding of the student experience in UGRI, focus groups were also conducted with all the students who completed the LS 187 courses. For all of the student focus groups, the students were divided into their respective groups (i.e., LS 187 A, B, and C) and the focus groups were conducted during the last class of each quarter. The student focus group protocol remained the same over the two academic years (see Appendix B for a copy of the student focus group protocol).

In order to understand faculty members' experiences and observations of student experiences, individual interviews were conducted with those faculty members who taught the LS 187 courses during the 2003-2004 academic year and/or 2004-2005 academic year. For all interviews, researchers used the semi-structured interview as it allowed them a certain level of flexibility and provided them with the ability to probe when necessary. The faculty interview protocol also remained the same over the two academic years (see Appendix C for a copy of the faculty interview protocol).

All student focus groups and interviews were audiotaped and transcribed. Following transcription, the analysis process consisted of reading and re-reading interview transcripts to develop a codebook containing analytic categories relevant to the issues at hand. Using the data analysis software program ATLAS.ti, the research team used these categories to code all of the interviews. A subset of interviews was coded by multiple researchers to ensure reliability across researchers.

Assessment Framework

The assessment framework was designed to guide the construction of the student survey, student focus group protocol, and faculty interview protocol (see Table 1). Students were asked about their background characteristics and motivation for enrolling in the course. The primary focus of the assessment, however, was to query the students as to how the LS 187 course had facilitated their interaction and learning, skill development, sense of community, and future plans for research. Students were also asked for suggestions for improvement of the course. Additionally, faculty was also interviewed about their observations of the student experience in the LS 187 course.

Table 1. Assessment Framework

Theme Heading	Student Experiences	Faculty Observations of Students
Student Profile	Gender, Ethnicity, Major	
Motivation	Why did you choose to take this course, and what did you hope to get out of it?	
Interaction and Learning	How did the lab activities, the students, and the instructors help you learn?	Do you believe the experience of doing real research as opposed to a more typical lab exercise engaged your students more deeply and helped them learn?
Student Skill Development	How has the course improved your ability to work collaboratively, present and teach, develop research skills, develop science competence, problem solving and critical thinking, and science confidence?	How has the course improved the students' ability to work collaboratively, present and teach, develop research skills, develop science competence, problem solving and critical thinking, and science confidence?
Sense of Community	Did the course help you develop a sense of community?	Does the course promote a sense of community among students?
Future plans	How has thinking about your own field of study been influenced by this course?	How do you think the course has affected the students' research aspirations/attitude toward research?
Suggestions for Improvement	What do you see as the challenges/problems of the course?	What were the challenges for the students?

Sample

There were a total of 84 student surveys completed (see Table 2). For the 2003-2004 academic year, all of the students who completed the LS 187 course in the spring 2004 quarter and five students from previous quarters participated in the assessment. For the 2004-2005 academic year, all of the students who enrolled in at least one quarter of the LS 187 series participated in the assessment. The findings are broken down by section: LS 187 A (n=55), B (n=13), and C (n=12). Four students did not report the LS 187 course in which s/he was enrolled and were therefore not included in the data analyses. The students were approximately half female and half male; however, the majority of the students were Asian American/Pacific Islander. Also, the vast majority of the students reported majoring in the life sciences.

Table 2. Student Characteristics for Survey Respondents

Student Characteristics	LS 187A (n=55)	LS 187B (n=13)	LS 187C (n=12)	All respondents (n=80)
Gender				
Female	28	5	5	38
Male	27	8	7	42
Ethnicity				
Caucasian/White	7	1	2	10
Asian American/Pacific Islander	36	9	7	52
African American	1			1
Chicano/Latino/a	2			2
Multiracial	4			4
Other or Unknown	5	3	3	11
Major				
Asian American Studies	1			1
Bio/Biochemistry	5	1	2	8
Biology	5	2	2	9
Biology/Marine	1			1
Chemistry	1			1
Math	1			1
MCDB*	32	4	1	37
MIMG[±] & Biochemistry			1	1
MIMG[±]	4		1	5
Molecular Biology			1	1
Physiological Science	2			2
Psychobiology	3	5	3	11
Psychology		1		1
Did not respond			1	1

*Molecular, Cell and Developmental Biology
[±]Microbiology, Immunology and Molecular Genetics

A total of four faculty members were involved in the teaching of the LS 187 course over the two academic years. Three of the four faculty members were interviewed for the evaluation. One instructor was not interviewed because s/he had left the university at the time of the interviews.

Results

Motivation for taking course

Students enrolled in this lab course because they wanted to develop research skills, learn more about the subject material and in some cases, satisfy a research requirement, and fulfill requirements for the major.

Table 3. Summary of Quantitative Results for Motivations for Taking Course (percentages)

	Not at all/ Just a little	Somewhat	A lot/ A great deal
LS 187A (n=42)			
Develop research skills	2	17	81
Learn more about the subject matter	5	17	78
Satisfy a research requirement	33	15	52
Fulfill a requirement for the major	36	46	18
Opportunity for hands on research	2	2	96
LS 187B (n=10)			
Develop research skills	0	10	90
Learn more about the subject matter	0	20	80
Satisfy a research requirement	56	0	44
Fulfill a requirement for the major	100	0	0
Opportunity for hands on research	0	10	90
LS 187C (n=8)			
Develop research skills	0	0	100
Learn more about the subject matter	0	0	100
Satisfy a research requirement	0	50	50
Fulfill a requirement for the major	43	14	43
Opportunity for hands on research	0	25	75
ALL STUDENTS (n=60)			
Develop research skills	2	13	85
Learn more about the subject matter	3	15	82
Satisfy a research requirement	32	18	50
Fulfill a requirement for the major	47	9	44
Opportunity for hands on research	2	7	91

Some students took the lab to satisfy a requirement and encouragement from an instructor. For example, one student noted:

> I chose to take this course because I actually got some information from my counselor. I'm an MCDB major, Molecular Cellular Development Bio. And I-- at the time had to fulfill [an] upper laboratory requirement, so I saw this as a good opportunity also. One of the professors I was actually taking a class with at the time, Professor [X], she was one of the co-coordinators, I guess. And she was telling me about it. And I was really interested in sequencing in general…

Other students mentioned being drawn to this course because of the opportunity to conduct research, "I took this course to get as much research experience as possible." Some students

expressed a desire to develop lab skills and noted the importance of have specific lab techniques under their belt.

Students often commented how this lab course was appealing to them because it provided hands-on lab experience and complemented other courses in the life sciences that were more conceptual and theoretical. This was also true in cases for where the subject mater was outside their major. One student described his experience through the progression of the three quarter course:

> So I wanted to get to know more about this type [of] research. And going through the basic courses like LS1, 3, and 4, etc., you learn all these different tools. But in order to apply these and to have a better understanding you actually physically have to do a research project. So at first I was kind of apprehensive to even do it because I thought I won't be successful, but as I went through the program it was really interesting seeing, using all the tools, everything you had learned, all the theoretical, and putting it to actual practice. And it was really interesting.

Interaction and Student Learning

In addition to motivating factors in choosing to enroll in the course, students were asked to comment on how various aspects of the lab helped them learn and to comment on their interactions with their fellow students and instructors. Three aspects of the lab are explored in this section: the lab activities, the students, and the instructors.

Lab Activities

Students indicated that the lab activities helped them learn (see Table 4). Many students found the class presentations helpful and that collaboration with other students and the lab experiments also helped them learn. The responses for students who had taken one, two, or three of the labs did not reveal consistent patterns. It is interesting to note that when students were asked to rate the value of collaborating with other students and the class presentations, the responses were higher for students in the first and second lab quarters as compared to the third, indicating that these activities proved more helpful to the newer students.

Table 4. Lab Activities (percentages)

	Was of no help/ Helped a little	Helped	Helped a good/ great deal
LS 187A (n=55)			
Class presentations	7	27	66
Collaboration with other students	9	29	62
Understanding each part of the experiment	4	22	74
LS 187B (n=13)			
Class presentations	8	39	53
Collaboration with other students	15	39	46
Understanding each part of the experiment	0	46	54
LS 187C (n=12)			
Class presentations	25	25	50
Collaboration with other students	25	25	50
Understanding each part of the experiment	0	58	42

ALL STUDENTS (n=80)			
Class presentations	10	29	61
Collaboration with other students	13	30	57
Understanding each part of the experiment	3	31	66

Students also frequently noted how they learned from each other. As one student said, "you've worked as a team in this course, and the results were dependent on working together by dividing up the sequencing experiment in stages, with the success of each stage dependent on the other." Students who had completed the three quarter lab sequence also noted how working in a team requires each member to contribute. One student noted:

> I think it's because it's not like any normal laboratory class where they have the lab set up for you and you're supposed to do like a certain experiment and get a certain result. Like the progress in this lab, it's your responsibility. So you want the lab to go well. So you need to understand what you're doing, and you want to make progress too during the quarters. So that gives you some incentive to do well.

Another student added:

> Well, we have other students looking out for each other because if one person makes a mistake, then it affects an entire experiment. And so there's this natural tendency to want to collaborate and then it becomes mutually beneficial, and it becomes a fun environment as well.

Faculty also observed the collaborative spirit in the lab. Over time, the lab became more organized and students became more efficient, "like a conveyor belt almost, like a factory." However, because of this structure, if one student was missing, then the whole process stopped. One of the challenges to accomplishing each day's research was to make sure that there were enough students to fill in every experimental slot. However, by creating specialization of tasks, students felt that they sometimes lost sight of the big picture and how each step relates to one another. Students also commented, though, that because they became a specialist in one area, they would be the one to explain to others what they did. As one student noted, "So you became an expert in a piece of it. So then you become kind of dependent on each other. I mean, if you're the expert."

Many students noted that they appreciated doing the experiment themselves as opposed to being given a guide that tells them what to do. For example, one student said:

> Well the point I'm coming to is that like she made us think independently, she didn't just hand us a notebook and say "This is how you do it, go push start, go to this program," and like, you know, go here and go there and go there. So it made me think on my own, it made me try to figure out the system, instead of reading it from a sheet and every single time coming back, looking at the sheet and figuring it out, it was just in my head and so on with that.

The "hands-on" aspect of the lab helped students learn and make theory and concepts something tangible. The students noted that this lab helped them pull all the information they had learned in other science classes together. As one student observed, "the hands-on work in the lab helps you pull it all together so it gels." Another student added:

> Applying whole concepts that you've learned in books will really help students. I think UCLA is really book smart but not really when it comes to a lab I think you don't really know how to do this, but hey you can read all about it but when you're actually doing it it's completely different. And that really interests me for this course. And I also think the size of the class, it's really small, like LS3, like a lot of LS core classes were really huge kind of don't feel connected, and you can't really talk to the professor, here we can actually talk to Dr. [X] and discuss about the things that are happening in the lab, where in LS3 you have a TA and you kind of feel disconnected to the research.

Most students also indicated that repetition of activity in the lab was useful and helped them learn. One student said:

> Another thing I was going to add is I like the fact that we did the same thing for a couple of weeks before switching. Because in 104, we did a different experiment every time and a lot of people, you know, I did PCR in that class and they did it once and they probably screwed it up and it was like you didn't really know what you're doing. Like we did PCR over and over again, so here I really, really like it.

Students particularly appreciated an environment where they could try new things and where it was okay to make mistakes. As one student reported:

> I felt I had freedom to make mistakes and just try new methods of doing things. Even though it was the same techniques over and over, we still had the freedom to do little changes here and there. And the fact that it was mostly student- initiated, I guess, made me more comfortable to try doing new things.

<u>Students</u>

In the lab, more advanced students were expected to mentor the newer students. The majority of the students found each other to be a useful resource and noted in the focus groups the importance of having the instructor explain what was happening if the other students could not. Table 5 presents how student interaction impacted learning. Students who had enrolled in more than one quarter of the lab sequence noted higher quality of contact with other students.

Table 5. Summary of Quantitative Results for Students (percentages)

	Was of no help/ Helped a little	Helped	Helped a good/ great deal
LS 187A (n=55)			
Students in other levels of the course	4	39	57
The quality of contact with other students	6	24	70
LS 187B (n=13)			
Students in other levels of the course	15	39	46
The quality of contact with other students	0	46	54
LS 187C (n=12)			
Students in other levels of the course	11	22	67
The quality of contact with other students	0	36	64
ALL STUDENTS (n=80)			
Students in other levels of the course	7	37	56
The quality of contact with other students	4	29	67

The students commented on the helpfulness of their peers during the focus groups. For example, one student noted:

> I think that a really good facet of this process is that you don't answer to professors. You answer to each other basically. For example, like the BLAST data that we have. We're each given BLAST data, and then there's one person, [student], who compiles all of it. So everything goes to him, and it's like a hierarchy of students. Rather than just giving something to the professor and saying, here's my work. And I think it helps a lot more when you're interacting with other people that you can relate with more, and relate to. So, I think that's really good.

Another student added, "Whenever I had a question, instead of bugging the TA or the instructor, I'll reach out and ask one of the C students. And so they really were helpful." Students also explained that they learned a lot by teaching. For example:

> You actually learn a lot more when you're the mentor. Because when I was an A student, one of the B students showed me a lot. But it wasn't until I became a B student that I actually put all that into practice.

Another student added:

> You also have other students asking you questions, and if you don't know it really well, then you realize that you need to go and ask the teacher. And so you learn as well. It tests you to make sure that you know everything.

Over time, students became more comfortable in the lab and learned what was expected of them and the role they would play in an experiment by working with each other. One student reflected:

> By the end of the first week, you're familiar with what you're supposed to do. You just have to get acquainted with how to do it, and then the B and C people will feel more relaxed at that point to tell you exactly the process or how to carry out the protocol. So it becomes collaborative, and it becomes more relaxed because now the A people have B and C people to rely on, and the B and C people can kind of rely on the A people to carry out what [they would] normally be doing if it was a quarter ago.

Again, collaboration helped students gain a deeper understanding and appreciation of collaborative practices. As another student so aptly stated:

> Every part of the process we had to be involved with other students, and in order for it to work and for you to understand what you're doing you have to be collaborative with your peers. So I think before this I probably had a lesser understanding of how research projects are actually done and how people work in groups as opposed to two. Afterwards, where you see the beginner students doing the stuff that you eventually are going to be analyzing, you see the whole process and how every person plays a part.

Students also revealed that the collaboration was facilitated by being with students who had taken the lab the quarter before. One student said, "we were familiar with each other." Another student elaborated:

> Well the good thing about this course now and being with these students is we have interacted in the first quarter, so now we are more familiar with each other and then altogether we've got a

> chance to actually help the A students, so there was more interaction than A, we're more confident and the time went by more pleasantly, plus we get to know how to joke about the genomic stuff and at the same time actually do some work. So that's why it's much better than the last quarter and overall the other classes, I mean this class is better than the other classes because of this type of interaction.

Another student commented that it was "like [having] your own personal tutor by your side." The instructors in the course indicated that student participation in the research helped to foster a sense of collaboration among the students. One instructor noted that the students paired up, and worked in teams. He noticed how the less advanced students learned from the more advanced students, and that there's a "learning and talking between them…there's camaraderie."

Students also noted the comfort with asking questions and the value of having so many individuals (students and faculty) to assist them. For example:

> The staff was very helpful. They were always available, more so than other lab courses. Also, it helped that there were many students, the B and C students who took it before. So, I felt comfortable asking any of them to help me if I didn't know how to do something. So, I always felt that there was always somebody I could ask, and never felt uncomfortable asking for help.

Instructors

In addition to their interactions with the other students in the course, students were also asked to comment on their instructors, quality of contact with the instructors, and the overall instruction and how it impacted their learning. Most students valued the contact with the instructors and were generally satisfied with the way the class was taught (see Table 6).

Table 6. Interaction with Instructors and Learning (percentages)

	Was of no help/ Helped a little	Helped	Helped a good/ great deal
LS 187A (n=55)			
The instructors	6	18	76
The quality of contact with the teachers	6	17	77
The way that this class was taught overall	4	24	72
LS 187B (n=13)			
The instructors	8	15	77
The quality of contact with the teachers	8	31	61
The way that this class was taught overall	8	23	69
LS 187C (n=12)			
The instructors	0	50	50
The quality of contact with the teachers	0	33	67
The way that this class was taught overall	8	50	42
ALL STUDENTS (n=80)			
The instructors	5	23	72
The quality of contact with the teachers	5	22	73
The way that this class was taught overall	5	33	62

Furthermore, students felt support for learning and felt that it was "ok" to make mistakes because as some students observed, "learning occurs when one makes a mistake." As one student revealed, "They never got mad at us if we messed up, so that was good. We could be wrong but they did not make us feel bad about it." Another student added:

> [Professor X] made it clear that if we made a mistake that we should write it down. And once we have that mistake written down, she said even though we might have to load it twice it was okay. It was okay to make mistakes; this was an ongoing process.

And, while it was an ongoing process, students were quick to realize that they could always turn to the faculty as resources. As one LS 187C student expressed:

> Well having [X] and [X] in the lab all the time, they're basically guiding us to a point where we're starting to guide ourselves, and then guide the B and A students. So, the quality of interaction between [the students and] Dr. [X] and [X] was really good. And then the few times that I actually visited Professor [X] in her office she was very receptive and very willing to just go off on a tangent or discuss things directly related to the course. So, it was good overall.

For the most part, the students valued the enthusiastic faculty. One student said, "You could see how passionate she is about this whole project and everything, through every day and every class, how excited she gets about it and it translates through the class." Other students observed that the faculty valued teaching the students over the research that was being conducted in the lab. One student observed: "I could see her priority is working with us and doing the research together, instead of her doing her own research and she had to teach us on the side.

Generally, the students commented that the faculty members were always available and created an environment that was intimate and not intimidating. For example students noted:

> It wasn't really much difference. Just that I feel like, you know, more expectation from the professor, as well as the one who's in charge of the lab, which is [X]. There's really more expectation, but then they make the transition really at ease, so I didn't really feel any pressure from them at all.

> Dr. [X], she was just in the lab right now and I was doing some makeup review, I mean they're wonderful, whenever you need them they're around, they'll stay over, they'll stay late, you can call them any time you want, and it's just a really intimate experience you have that I've never had with any other professor in UCLA.

Student Skill Development

This section presents how students' skills have changed as a result of participating in this lab course. Variables of interest include collaboration skills, presentation and teaching skills, research skills, science competence, problem solving skills, and science confidence.

Working Collaboratively

As mentioned earlier, the lab required students to work together. As a consequence, most students noted that they learned a great deal by working with other students, and that over time their collaboration skills grew and they got better at working with each other. Table 7 presents data on whether or not the lab developed collaboration skills. The development of collaboration skills is higher for students in LS187A and LS187B, indicating that most of their collaboration skills were developed earlier in the course sequence.

Table 7. Collaboration Skills (percentages)

	Not at all/ Just a little	Somewhat	A lot/ A great deal
LS 187A (n=55)			
Skills in collaboration	7	24	69
LS 187B (n=13)			
Skills in collaboration	8	39	53
LS 187C (n=12)			
Skills in collaboration	17	50	33
ALL STUDENTS (n=80)			
Skills in collaboration	9	30	61

The students learned quickly that the collaborative nature of this lab was an efficient way to coordinate the lab activities. A few of the students, however, indicated that they preferred working alone and found working with others very challenging. One student said:

> I think for me it was difficult because I work in another lab where I do my own thing, and so to depend on other people to be able to do their thing and for me … I'm a control freak and I have to do things by myself.

For the most part, however, students learned about the collaborative nature of science and making sure you "contribute your part." One student commented, "I think you become more responsible for your own actions, since everyone depends on your work. You become more responsible, then in some way your data will become more reliable. It's about trusting, too, from your colleagues." Another student described sharing responsibility, "I think this class is just a lot about personal responsibility. You have to kind of own up to your own faults, if you happen to mess up on a certain experiment."

Throughout the assessment, students continued to comment on how collaboration requires each person to contribute to the lab work. The more senior students enjoyed teaching the newer students and realized they really needed to understand the material to teach it. They noted that they gained a deeper understanding and appreciation of collaborative practices because of this course. One instructor summarized the increasing importance of being able to work with others:

> Teamwork, they say, is now an essential component of the life sciences and I agree. In my research, I'm in more and more collaborations than I was five years ago. I see this type of course as what we need in order to be able to communicate, we need that professionalism, accountability, this kind of thing, and just the ability to work with one another. I think we really tried to cultivate that in LS187 as well.

Faculty who taught in the lab noted how their students were collaborating and valued being part of a community. Another instructor felt that participating in this research helped students to foster a sense of collaboration among their peers and to work as a team. He added that students became dependent on each other as they each developed an expertise critical to the experiment.

In short, students felt connected. As one student said, "You go to office hours, so I see we're able to feel a togetherness, like we feel like this is already- it's like a natural thing, to feel connected to the other students and the professor." In the focus groups, students indicated that this lab was a great preparation for the real world. As one student explained:

> I think it's a perfect way to prepare the students to go out and-- because that's what being outside-- that's what the reality is that you go outside and you've got to work with people. And so, it's perfect prep for that

Students indicated an ability to connect their work to the big picture and that their piece of the work was essential. For example, "You do your work and others build on it." Another student added: "So it's like a chain of events and each of you were playing a role." The faculty supported the collaboration and observed students helping each other out. One instructor noted:

> I watched then sort of tag team. Watching them negotiate. They knew what the goal was and- what each person would do. So they communicated pretty well with each other.

Presentation and Teaching Skills

The lab also provided a setting for students to present and teach, and most students noted gains in these areas (see Table 8).

Table 8. Presentation and Teaching Skills (percentages)

	Not at all/ Just a little	Somewhat	A lot/ A great deal
LS 187A (n=55)			
Skills in presentation	10	40	50
Skills in teaching others	11	25	64
LS 187B (n=13)			
Skills in presentation	0	0	100
Skills in teaching others	0	0	100
LS 187C (n=12)			
Skills in presentation	0	38	62
Skills in teaching others	0	13	87
ALL STUDENTS (n=80)			
Skills in presentation	6	31	63
Skills in teaching others	7	18	75

The lab required students to present and the more senior students frequently served as instructors to the newer students. As a result, students noted that they developed their presentation skills in this class. As one student described:

> We have to present each week, each of us would take turns presenting a part of a chapter, or finding an article and presenting all that information. And you have to kind of understand the material first before you can teach the rest of the class.

Students commented that their teaching skills grew as result of participating in the lab, "You learn patience, because we have to teach other. Patience for others and patience for yourself." While the LS 187C students probably had the most opportunities to teach their peers, the students who had taken LS 187A and B also felt that there were several opportunities for them to teach other students and used a variety of strategies to help students learn. For example, one student described:

> I think that you basically break it down to the basics, use colloquial terms, simple terms. You explain it how you would like it explained, very simply. You don't want to use all these verbose and bombastic words to explain all these. I know there are scientific terms to explain certain phenomena etc., but I just explained it so that it was really easy and to the point…You can only teach something if you're confident in the techniques or the process.

Another student described her teaching experience and the importance of practice:

> I think for me there are different experiences I had in terms of teaching. One is the actual cause. What I do is analyze gel. So when they ask me to teach somebody how to analyze gel I would sit down and go through…this is what I look at, this is what I look for. And then they're like; oh you're going too fast. Then I have to start over again. And then you basically do what you're doing, but just slow it down and tell them what you're doing as you're doing it. And that's kind of my approach. So I sat them down and I explained it, the way that we were explained, and I brought out books and stuff we used. I'm sure it made sense, but it didn't click until they were actually doing it themselves. So I think that in practice you learn way more than if somebody is just telling you.

Students recognized that they were "doing what researchers do." They were studying the literature, presenting findings to ones colleagues, and creating posters on their research. Some students touched on the importance of listening to others:

> We each do a presentation. Like every student does a presentation. So that-- we'd each learn like a certain article in -depth, and then we're present it to the rest of the students. So, I think that was cool like how all of us would be able to listen to each other, and teach each other about our own topic.

<u>Research Skills</u>

Many students reported that the lab helped them develop their research skills, especially understanding data. The data also suggests that students who were newer in the lab sequence were more likely to report greater change in their research skills (see Table 9).

Table 9. Research Skills (percentages)

	Nothing/ Just a little	Somewhat	A lot/ A great deal
LS 187A (n=55)			
Research skills both in the laboratory and on the computer	7	26	67
Understanding data	9	20	71

LS 187B (n=13)			
Research skills both in the laboratory and on the computer	0	31	69
Understanding data	0	39	61
LS 187C (n=12)			
Research skills both in the laboratory and on the computer	0	55	45
Understanding data	0	58	42
ALL STUDENTS (n=80)			
Research skills both in the laboratory and on the computer	5	25	70
Understanding data	6	29	65

As the students became more involved in the research, some remarked on how the research process is repetitive, takes a long time to unfold, is tedious, and requires precision. However, many of the students also realized the appealing aspects of research as well. As one student said, "This repetition piece is particularly helpful because it reinforces it and you have many chances to do that." Another student noted, "I think the main thing that I got out of this class is that it's a lot of toil. It's a lot of repetitiveness." And yet a third student added, "You're not extremely riveted while you're doing the project, but, after it's done, you look back and it's probably really rewarding to know what you've done. And what all you've accomplished through all your hard work." For the most part, students remained engaged in the research process because they understood the objective of the project. As one student revealed:

> I think one of the good things about the class is that you get to see the whole beginning to end, and I worked in a research lab before and I totally lost interest in the research and I gained the respect for the researcher and what they do but like you kind of do the little things and never get to see the big picture. And I think one of the great things about this course is that you get--although you make a lot of mistakes and make up 10 weeks, you get to many and you get to work with it and you see everything as well.

One faculty member noted that the students valued repeating the same techniques and that the repetition is what led to mastery. This professor shared the following:

> I think the thing that they have told me that I think is really nice is that they feel like they master certain techniques and I think because they do them over and over and over which is something they don't get in a traditional lab form where they just do one type of experiment every week and three weeks later they would not review the same thing again. Here they are able to acquire a core set of skills and I think that that gives them some confidence that they can in other situations, given the time, they could do it too so I think that's been good.

Faculty also noted that students developed research skills that even some graduate students do not have. Faculty added that students used these newly-acquired skills to get jobs in industry and, in some cases, caused them to consider research as a profession. One professor observed that some students changed their attitude about conducting research, realizing that it can be fun. Another professor noted satisfaction with seeing students develop confidence, independence, and a "can do" attitude in the lab.

Science Competence

Most students indicated that their knowledge of science was positively impacted by participating in this lab (see Table 10). Not only did students indicate that they made gains understanding the main concepts and the relationships between theory and practice, they also indicated feeling more comfortable with science research.

Table 10. Science Competence (percentages)

	Not at all/ Just a little	Somewhat	A lot/ A great deal
LS 187A (n=55)			
Understanding the main concepts	4	26	70
Understanding the relationships between theory & practice	6	22	72
Understanding the fundamentals of genomic biology	7	22	71
Confidence in your ability to use computer-based tools for Biology	7	26	67
Feeling comfortable with science/research	4	29	67
Understanding the process of science	4	33	63
Ability to be conversant about genomics	6	29	65
LS 187B (n=13)			
Understanding the main concepts	0	23	77
Understanding the relationships between theory & practice	8	15	77
Understanding the fundamentals of genomic biology	0	23	77
Confidence in your ability to use computer-based tools for Biology	8	23	69
Feeling comfortable with science/research	0	31	69
Understanding the process of science	0	31	69
Ability to be conversant about genomics	8	23	69
LS 187C (n=12)			
Understanding the main concepts	0	42	58
Understanding the relationships between theory & practice	0	58	42
Understanding the fundamentals of genomic biology	8	33	59
Confidence in your ability to use computer-based tools for Biology	0	58	42
Feeling comfortable with science/research	0	50	50
Understanding the process of science	8	42	50
Ability to be conversant about genomics	0	58	42
ALL STUDENTS (n=80)			
Understanding the main concepts	3	28	69
Understanding the relationships between theory & practice	5	26	69
Understanding the fundamentals of genomic biology	6	24	70
Confidence in your ability to use computer-based tools for Biology	6	30	64
Feeling comfortable with science/research	3	30	67
Understanding the process of science	4	34	62
Ability to be conversant about genomics	5	33	62

Many students talked about how the lab helped them raise their level of awareness of genomic biology and deepened their theoretical understanding of what they gained from other courses. For example, one student said, “It's like we learned PCR in LS3, and now, without anyone preparing the gel or anything for you, you do it on your own.” Students also revealed that the lab helped them appreciate more “those that discover.” Another student aptly stated:

> In terms of the steps and the procedures, we’re able to realize if we mistakenly leave out a step the consequences it’ll have. And in terms of carrying out the procedure, after having committed so many mistakes you realize what is really detrimental, what you can get away with, why it is you have to add this, and what happens if you don’t, how the data is going to look if you do this.

When students were asked how much they had learned in this course compared to other courses they had taken in terms of subject content, the responses were mixed. Some students indicated that compared to other courses, they found the course repetitive and boring. Other students noted that the lab was focused on one thing and they learned that one thing very well. For example, one student commented:

> I don’t think I’ve learned a whole lot more, but I think I’ve gained a better understanding of a small base of knowledge that was kind of thrown at me, and some of the courses I’ve taken. I think just in terms of genomics in general, the scope of the class isn’t like that big, but it’s really focused, I think.

Almost all the students commented on how they learned about genomic research and how it can be useful. Students noted:

> I think what we learned about it is that getting involved and how the sequencing and I can see the genes and you are capable of learning and applying those genes, being able to define for example genes that are related with other organisms and see for example how these genes can-- the product of these genes can actually help us. For example, in pharmaceuticals, being able to--in our case we're dealing with a material that is capable of sustaining high temperatures. So if we know for example how it's doing that, if you know what it's changing, how it's making the protein to be so stable at high temperatures we can apply that and use it to other organisms and get an understanding of how proteins will function.

> I believe what it comes down to is just a lot of diseases derived from the mutation of the genetic code. And yeah, it really comes down to the level of the seeing codons and nucleotides. So, if you mess up one of those things, and basically, you know, check. In general, though, genomic research is really important right now, because you can actually, now they're doing a lot of genes transplantation now. And they can transplant it to a certain promoter and then they can make it,_ rescue the genes from not expressing, that changes, because there are some genes that get mutated and they don't get expressed. But however, if we can rescue it, and it can express that, it probably help in some way, you know. So studying the changes of that.

Students valued the opportunity to apply in the lab what they learned in other courses. One student observed that, “applying what you learned in other classes really helps you understand the concept and theory. One student added:

> I think I always had an idea of what it meant, but I never saw how it all connected. This class really showed me how the topics that I learned in LS-3 and LS-4, how they all relate to the bigger picture. And I think that was the most helpful part. I never understood why we were learning it until this class.

Faculty also observed students making connections between courses and using what they learned in other course in this lab. One professor concluded: "So that's kind of cool that he's able to take what he learned from here, and take it somewhere else.

Problem Solving and Critical Thinking

Students also developed their problem solving skills and critical thinking skills in the lab (see Table 11). The lab helped students think in different ways, and as noted earlier, use what they learned in other classes in the lab. This last variable, using what you learned in other classes in the lab, was more pronounced for students enrolled in LS 187A and LS187B, indicating again the importance of initial exposure to hands-on research. Both surveys and focus groups revealed similar results for these variables.

Table 11. Problem Solving and Critical Thinking (percentages)

	Nothing/ Just a little	Somewhat	A lot/ A great deal
LS 187A (n=55)			
Solving problems	22	22	56
Ability to think through a problem or argument	15	35	50
Ability to think in different ways	13	31	56
Ability to bring together/refer to knowledge you acquired in other courses in the context of the research experience	0	17	83
LS 187B (n=13)			
Solving problems	31	39	30
Ability to think through a problem or argument	15	39	46
Ability to think in different ways	17	25	58
Ability to bring together/refer to knowledge you acquired in other courses in the context of the research experience	0	20	80
LS 187C (n=12)			
Solving problems	18	46	36
Ability to think through a problem or argument	8	42	50
Ability to think in different ways	17	33	50
Ability to bring together/refer to knowledge you acquired in other courses in the context of the research experience	0	38	62
ALL STUDENTS (n=80)			
Solving problems	23	28	49
Ability to think through a problem or argument	14	36	50
Ability to think in different ways	14	30	56
Ability to bring together/refer to knowledge you acquired in other courses in the context of the research experience	0	20	80

The focus groups revealed that the students appreciated the instructors and how they guided them through problems with work in the lab. One student noted:

> If there was a problem, we talked to each other. Also talking to Dr. [X]. She kind of just walked us through like if a thing would go wrong, why did that happen and then, you know, just kind of discuss more about how we could fix it, and then try it.

Students noted that they developed troubleshooting skills over the course of the class. Students especially enjoyed their independence:

> But you know what you have to do. So you can schedule all your time. It's just is going to work. If you're researching this is basically what everybody does outside of school. You just go to work. You know what you have to do the day that you have to work, and you're doing- you do everything. You follow step-by-step. So this is what was good about this quarter. You know, we had our project. We came in. We did what we had to do, or we'll take the break that we needed.

Faculty observed students' growth in analytical and critical thinking. One professor facilitated students figuring out how to solve a problem and noted the following:

> Students developed analytic and critical thinking. Because what happens is that I give them sort of like a little review each time, so when they're doing a sequencing reaction, they've got to know the job, and if it doesn't look right, they call me over and I go, o.k., so what do you think is wrong with this picture? Or do you think it's fine? And they'll say, no. There's something wrong. So I ask them, what's wrong with it? Can you tell me what's wrong? And they'll say something. And I'll go, why do you think that's so? And so instead of like rather me telling them what's going on. And so they're really smart with that. They need that. So I try to support them. So like, you know, anything that happens I kind of have to like go, what would you do to create a better situation, working environment. And they'll come up and say, you know, we can probably do this differently or work a lot faster if we do it this way. And I go, o.k., why don't you try it? And then let me know how that works? And they go try it and go, yeah. Then if it works, then I try to support what they've done. You try and get them to figure it out.

Science Confidence

The focus groups revealed that most students also developed science confidence in this lab; again, this was most notable for students who spent more than one quarter in the lab. Students often described that this confidence grew as they learned more and mentored the newer students. Students also observed how their comfort with the lab changed. For example, one student said:

> Before I came into this class I was actually really…whenever I'd do something in a lab, I'd ask, "Am I doing this right?" I'm always kind of shaky, and I'm not sure what I'm doing. But I'm taking a lab right now. After the second quarter of taking this, I don't really second guess myself that much anymore. I'm pretty confident in what I'm doing. And there's no uncertainty and shakiness that there was before.

The teaching and mentoring aspects of the lab helped students develop independence and science confidence. For instance, another student described:

> I know students are independent learners here in the university, but I think we've become more independent, especially [because] you don't want to always constantly ask [Dr. X] and [Dr. X] etc. You become more independent. You try to learn by either observing your peers, asking questions, and then even resorting to ask [Dr. X] how to do something. Yeah, I think this makes you more of an independent learner and you have to become confident in your abilities when you're actually doing the wet lab or analyzing the gel or doing a blast.

The more senior students noted that the course helped them to become a "specialist" in a specific area, which in turn made them more confident about their research skills. For example:

> I think that in our lab there are sort of specialists in each area. So like I'll go to [this particular student] if I need help with loading a blast or I'll go to [another particular student] with the data that they get or - and what I do is the gel. So it's like in each situation there's been sort of [an expert that] has been doing it for the whole time and they know what they're doing.

Many students were also very excited to be part of a research team that was contributing to science. Students noted that this aspect of the lab was very motivating and they liked the idea that their work would some day get published. As one student noted, "In the other classes, we just learn the concepts and. In this one, we have to contribute something." Another student added, "Exactly. This is your own work, you really want to see where it goes." Other students noted how excited they were to get published and that they wanted to see what happens with the genome project.

Sense of Community

Over the course of the assessment, it became evident that students appreciated the interaction with students and instructors in the lab, and because of the collaborative nature of their work, over time started to develop friendships. One student noted the following:

> I was hoping to get some research experience, most definitely. And then I thought that this class helped in the sense of working with other people because you have to depend on someone else who does their job right so that you can also complete your job, because we all work together in different tasks. I think that's really how a research lab does work, where you take samples from someone else that supposedly did it correctly so you can do something else to fulfill your job. I really liked being able to work with everyone for this lab.

Some students indicated that they made lifelong friends in this course that they will stay in touch with after the course is over. One student said: "I have developed relationships that will be part of my network." Faculty also observed this sense of community among the students, adding that the nature of the course had students interacting all the time:

> There was a real sense of community up there, yeah, absolutely, and they wanted to socialize and I think they did make some friends. Yeah.

Impact on Future Research Plans

In regards to the future, students had different views on how the course impacted their research plans (see Table 12). Generally, students believed that the lab positively impacted their plans to work in a lab in the future and conduct research in the life sciences. The results for whether or not the lab impacted students plans to do graduate work involving a lab were mixed, especially for the LS187 C students.

Table 12. Future Research Plans (percentages)

	Not at all/ Just a little	Somewhat	A lot/ A great deal
LS 187A (n=55)			
Working in a lab in the future	2	7	91
Graduate work involving lab work	5	34	61
Conducting research in the life sciences	7	14	79

LS 187B (n=13)			
Working in a lab in the future	0	22	78
Graduate work involving lab work	0	44	56
Conducting research in the life sciences	0	33	67
LS 187C (n=12)			
Working in a lab in the future	13	25	62
Graduate work involving lab work	25	13	62
Conducting research in the life sciences	13	50	37
ALL STUDENTS (n=80)			
Working in a lab in the future	3	12	85
Graduate work involving lab work	7	33	60
Conducting research in the life sciences	7	22	71

For many students, the course did not change their research plans. For example, one student said, "Well, I'd like to go into professional school after I graduate, but I don't know. It might help, but I'm not sure how genomic research can help later on in life." Another student added, "I couldn't say this class had a big impact in that decision. I've interned in research labs before, so I think that had a bigger influence than this class."

The focus groups revealed that for other students, particularly those that had taken the entire lab sequence, their future research plans were affected significantly. For example, one student stated:

> I think because of this experience I've been way more open to -- I used to think research is something you have to do. But now it's something I like, and after this is over I'm going to try to find another research position because I like it, and I might want to continue doing it even when I'm older. I have no idea, but because of this I have a better view on research.

Regarding the future, some students wanted to continue with this research and in some cases maybe not genomic research but research in another area in industry. Other students noted that it helped them in interviews for other research positions. The faculty also noted some changes in student aspirations. One professor indicated the following:

> One student in LS 187-C already- and B was already in the winter talking to me about well, I want to go to the Sanger Institute, I was fishing around on the web and I saw this fellowship for undergraduates in England at this big institute with DNA sequencing and he put in an application for that and he didn't get it which doesn't surprise me because I think the British kind of take care of the British undergraduates, but I did get him set up at JGI, Joint Genome Institute, in Walnut Creek for the summer.

Suggestions for Improvement

Some of the students and faculty noted that the lab was impacted by the motivation and interest level of the individual students. For example, there was one individual who came to class late in the beginning and did not participate fully in the lab. In response, one of the instructors talked with the student, and from then on s/he became a paragon of punctuality. One professor indicated that by the third quarter, they had developed a system to closely monitor and grade student work and that this would be used next year. Students also expressed a need for more faculty lectures that would bring together the work conducted in the lab. As one professor noted:

> In the coming year, we're going to introduce a lecture component and we're going to make it truly interdisciplinary in terms of that everyone's going to understand the optics behind the sequencer and the chemistry and the mathematics that is involved in that particular bio-infomatics experiment.

There was some frustration with students who did not carry their weight in the lab. For example:

> I just hope to have serious students coming in, not really just take it lightly, and I don't know, probably cater to the serious students more than- but cause you don't want people coming in who don't really care when you help to get it off the ground and you really care.

As a result of the first-year experience, the professors developed a system to monitor student work that was implemented in the second year. When there are 20 students doing different things, instructors cannot keep track unless it is written down in a log book. This was also necessary to ensure that students take full advantage of all of the different types of experiments in the LS187 course; some students had the tendency to want to specialize, because it was easier to master only one experimental technique than learning to become proficient in all.

For the most part, students expressed a desire for more lab time. One student said, "It sometimes feels like we are borrowing space." The instructors recognize the problem and in fact, they cannot obtain more lab time for the students because of lack of funding. Indeed, many students interested in the second year were turned away because there was not enough available lab space to enroll more students. Students observed that this was a problem. A couple students expressed a desire to have similar labs but in different subjects. Most students appreciated the committed and knowledgeable instructors. In the future, instructors noted an interest in providing more structure for students and requiring them to sign up for certain hours every week.

Discussion and Future Efforts

Student learning in the LS 187 course was enhanced by the various laboratory requirements and activities such as class presentations, collaboration with other students in the course, and hands-on participation in the laboratory. LS187 is unlike any other lab or lecture course; there is no template or precedent for a core course in a large-scale undergraduate research project. Some of the students sensed the disorganization and uncertainty of a pilot course and reported feeling confused in the beginning. This was more apparent in the first year the lab was offered. However, as the course progressed, many of the students found the lab activities beneficial and reported that they aided in their learning. In fact, students who were newer to the course reported finding the lab activities more helpful than those students who had continued on for three quarters, indicating that the greatest gains seem to appear early in the process.

Student skill development was assessed in the areas of collaboration, presentation and teaching skills, research and analytical skills, science competence, and science confidence. Many of the students felt that they learned from their peers through collaboration, and also that they became more skilled at being able to work cooperatively in groups. They reported positive gains in presentation and teaching skills due to the numerous opportunities to present or explain a chapter or article to an individual student or lab as a whole. Students also felt that the lab helped them to develop their research and analytical skills, especially in sequencing a microbial genome. As a

result of their experiences in the course, students felt increased science competence as well as increased science confidence.

Many of the students were excited to be part of a research project that was contributing to science. In fact, the research completed by the students in the LS 187 course will eventually be published and all of the data deposited with the National Center for Biotechnology Information, the database used daily by millions of researchers worldwide. This unique experience had varying effects on the students and their future research plans. Some students found the repetitiveness of the research boring, while other students enjoyed it because it gave them a chance to become really skilled at doing genomics research. As a result, for some the course had no impact on their plans at all, and in some cases made students realize that they did not want to do research in the future. For others, the course had a very positive impact and made these students realize that research was the path for them. In either case, students found a new appreciation for what researchers do in the laboratory and why certain discoveries can take so long.

As in all pilot years of a new curricular initiative, there were some challenges along the way, which gave rise to suggestions for improvements for future courses. Both students and faculty recognized that the lab's effectiveness was dependent upon the motivation and interest level of its students. In the first year, a few students as well as instructors noticed that certain students just did not pull their weight in the lab (e.g., always coming late to class), a detrimental effect when the success of the whole project is contingent upon all participants doing their parts. As a result, the instructors developed a system to monitor and grade student work, including effort and professional conduct that will be used again next year. Another challenge mentioned by one of the instructors concerns the lack of structure in scheduling and coordinating the numerous students with the many lab tasks. This same instructor recommended implementation of a log book to track students to ensure that all students get a chance to do everything in the lab.

The LS 187 series has improved the UCLA life science curriculum by providing opportunities for students to engage in active learning and inquiry based life science research. Students who participated in the LS 187 lab were pushed to think independently and work cooperatively. Students indicated that presentation, research, and analytical skills improved as a result of participating in the lab. Finally, students noted feeling more connected to their learning experience in the lab and that they could see why the work they were doing was important and useful. Students used new technologies in the lab and came to understand what researchers do in a life science lab, some resonating to this type of work more than others, but many developing a greater understanding and comfort with conducting research.

References

Boyer, E.L. (1990). Scholarship Reconsidered: Priorities of the Professoriate. Princeton, NJ: The Carnegie Foundation for the Advancement of Teaching.

The Boyer Commission on Educating Undergraduates in Research Universities. (1998). Reinventing Undergraduate Education: A Blueprint for America's Research Universities. Stony Brook NY: Stony Brook University.

Hakim, T. (1998). Soft assessment of undergraduate research: Reactions and student perspectives. Council on Undergraduate Research Quarterly, 18, 189-192.

Kerfeld, C. A., Levis, M., & Perry, L.J. (2001). Teaching and Exploring the Social Implications of Twenty-First Century Molecular Biology in a Laboratory-Based General Education Course. Innovative Higher Education, 26(2), 87-102.

Mabrouk, P. A., & Peters, K. (2000). Student perspectives on undergraduate research (UR) experiences in chemistry and biology. Spring 2000 CONFCHEM: http://www.ched-ccce.org/confchem/2000/a/mabrouk/mabrouk.htm.

Manduca, C. (1997). Broadly defined goals for undergraduate research projects: A basis for program evaluation. Council on Undergraduate Research Quarterly, 18, 64-69.

Nagda, B. A., Gregerman, S. R., Jonides, J., von Hippel, W., & Lerner, J. S. (1998). Undergraduate student-faculty research partnerships affect student retention. Review of Higher Education, 22(1), 55-72.

National Institute of Education (1984). Involvement in Learning: Realizing the Potential of Higher Education. Washington, DC: National Institute of Education.

National Research Council (2003). Bio 2010: Transforming Undergraduate Education for Future Research Biologists. Washington, DC: The National Academies Press.

APPENDIX A
Student Paper Survey

Name: _____

LS187 courses taken (Circle all that apply)**:** **A** **B** **C**

Quarter course taken: **Fall** **Winter** **Spring**

Gender: _____ **Major: _____**
Ethnicity: _____ **College GPA: _____**

Instructions to students: Circle one answer for each question on each scale: **NA = Not Applicable; 1 = lowest rating to 5 = highest rating.** You may add a comment for any item on the last sheet. Number your comments by the same numbers as the items in the questionnaire.

PART 1: MOTIVATION FOR ENROLLING IN COURSE

Why did you enroll in this course?

	NA	Not at all	Just a little	Somewhat	A lot	A great deal
14. Develop research skills	NA	1	2	3	4	5
15. Learn more about the subject matter	NA	1	2	3	4	5
16. Satisfy a research requirement	NA	1	2	3	4	5
17. Fulfill a requirement for the major	NA	1	2	3	4	5
18. Opportunity for hands on research	NA	1	2	3	4	5

PART 2: ASSESSMENT OF STUDENT LEARNING GAINS

How much did learning each of the following aspects of the class HELP YOUR LEARNING?

	NA	Was of no help	Helped a little	Helped	Helped a good deal	Helped a great deal
19. How did the laboratory deepen your theoretical (classroom-based e.g. your major coursework) understanding?	NA	1	2	3	4	5
20. The pace at which we worked	NA	1	2	3	4	5
The lab activities						
21. Class presentations (including lectures)	NA	1	2	3	4	5
22. Collaboration with other students	NA	1	2	3	4	5

23. Understanding each part of the experiment	NA	1	2	3	4	5

Resources

11. Students in other levels of the course	NA	1	2	3	4	5
12. The instructors	NA	1	2	3	4	5

Support as a learner

13. The quality of contact with the teachers	NA	1	2	3	4	5
14. The quality of contact with other students	NA	1	2	3	4	5
15. The way that this class was taught overall	NA	1	2	3	4	5

How much has this class ADDED TO YOUR SKILLS in each of the following?

	NA	Nothing	Just a little	Somewhat	A lot	A great deal
16. Solving problems	NA	1	2	3	4	5
17. Research skills both in the laboratory and on the computer	NA	1	2	3	4	5
18. Understanding data	NA	1	2	3	4	5

To what extent did you MAKE GAINS in any of the following as a result of what you did in this class?

	NA	Not at all	Just a little	Somewhat	A lot	A great deal
19. Understanding the main concepts	NA	1	2	3	4	5
20. Understanding the relationship between theory and practice	NA	1	2	3	4	5
21. Understanding the fundamentals of genomic biology	NA	1	2	3	4	5
22. Ability to think through a problem or argument	NA	1	2	3	4	5
23. Confidence in your ability to use computer-based tools for biology	NA	1	2	3	4	5
24. Feeling comfortable with science/research	NA	1	2	3	4	5
25. Understanding the process of science	NA	1	2	3	4	5
26. Interest in the topics discussed	NA	1	2	3	4	5
27. Skill in collaboration	NA	1	2	3	4	5
28. Skill in presentation	NA	1	2	3	4	5
29. Skill in teaching others	NA	1	2	3	4	5
30. Ability to think in different ways	NA	1	2	3	4	5
31. Ability to be conversant about genomics	NA	1	2	3	4	5
32. Ability to bring together/ refer to knowledge you acquired in other courses in the context of the research experience	NA	1	2	3	4	5

PART 3: FUTURE RESEARCH PLANS

To what extent are you interested in the following areas as a result of what you did in class?

	NA	Not at all	Just a little	Somewhat	A lot	A great deal
33. Working in a lab in the future	NA	1	2	3	4	5
34. Graduate work involving lab work	NA	1	2	3	4	5
35. Conducting research in the life sciences	NA	1	2	3	4	5

PART 4: GENERAL COMMENTS AND SUGGESTION FOR IMPROVEMENT

36. General comments about the quality of this type of course
37. Do you have any suggestions on how this course may be improved? If so, what?

*Based on one created by Elaine Seymour, Director of Ethnography and Evaluation Research, at the University of Colorado, Boulder.

Email Invitation for Student Web Survey

Dear student,

UCLA is always looking to create courses that are interesting to students but also provide a great learning experience for everyone involved. The Office of Undergraduate Evaluation and Research (OUER) at UCLA was created to help the College obtain feedback regarding their courses.

We are contacting you because you were previously enrolled in the LS 187A and LS 187B courses (Research Experience in Life Sciences). As you recall, these courses involved hands-on research in the laboratory. In order to learn more about your experience in these courses, we ask that you please complete the following survey. The link to the survey can be accessed at:

http://CTLSilhouette.wsu.edu/surveys/ZS25321

Your comments will be kept anonymous and you will never be directly identified. However, your comments may be used in our write-up as we discuss the opinions regarding this course. There are no right or wrong answers. Your comments will be used to help guide the way this course is organized in the future.

The brief survey should take approximately 15 – 20 minutes to complete. We really appreciate your participation.

Sincerely,

Marc Levis-Fitzgerald & Nida Denson

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Student Web Survey
(In addition to the questions on the student paper survey)

1. Why did you choose to take the LS 187A course?

2. Why did you decide not to continue in this series (i.e., LS 187B, LS 187C)?

3. Was there anything different/special about the quality of your interaction with the instructors, the students in the other sections of the course (LS 187A,B,C), and your peers in this class as compared to other courses you have taken?

4. How did the collaborative nature of the course influence your learning?

5. This course emphasizes hands-on and peer-mentored learning rather than instructor-based learning. How did this contribute to your overall experience in the course?

6. How did you find the mentorship experience? What were the associated challenges?

7. Has this course raised your level of understanding of genomic biology (yes/no)?

8. How has this course influenced your perception of scientific research and how scientific progress is made?

9. How has your thinking about your own field of study been influenced by this course?

10. Has this course made you more confident about your research skills (yes/no)?

11. Did the fact that you were doing real scientific research as part of this course influence you? Would the class be just as effective with "canned" labs in which the outcome is known?

12. Did your experiences in this course help you to develop your troubleshooting skills?

13. Is there anything else we haven't already talked about that you feel you have gained from this class?

If you have any questions or comments, please feel free to email either one of us.
Thank you for your time and your thoughts on this course.
Your comments will be helpful to future course development.

APPENDIX B
Students' Focus Group Protocol

Introduction (~ 2 minutes)

A. Introduce yourself

Hi, I'm from the Office of Undergraduate Evaluation and Research and one of the things we do is help Letters and Science gather feedback regarding their courses.

B. Preface discussion

UCLA is always looking to create courses that are interesting to students but also provide a great learning experience for everyone involved. So we're here today to ask you some questions regarding your opinions and experiences in this course. We hope to have an open discussion based on your opinions, comments and experiences regardless of whether they are good, bad or neutral. All your thoughts are very important to us because there are no right or wrong answers here and we want to hear everything you have to say. Your comments will be used to help guide the way this course organized in the future.

Our discussion should last about 45 minutes.

C. Set ground rules

Before we begin, let's set out some ground rules:

1. All your comments will be kept relatively anonymous. We will never identify you directly, however, your comments may be used in our write-up as we discuss the opinions regarding this course.
2. Again, there are no right or wrong answers. There may be differences in opinions, and in fact, we're hoping there will be. Please share any comments with us and don't worry if they're not what your neighbor is saying. Conversely, if you agree with your neighbor, we want to know that too.
3. Speak up clearly and talk one at a time. We're recording this session because we don't want to miss any of your comments, but the recording has a tendency to get garbled if more than one person speaks at once or if you speak too quietly.

D. Questions? If not, let's get started.

Questions

Motivation and Goals (~5 minutes)

1. Let's start by going around the group so that each of you can tell us why you chose to take this course.
2. When you began the course, what did you hope to get out of it?
   a. How did this course meet or not meet these goals?
   b. What helped to facilitate or prevent accomplishing them?

Interaction and Collaboration (~10 minutes)

1. Was there anything different/special about the quality of your interaction with the instructors, the students in the other sections of the course (LS

187A,B,C), and your peers in this class as compared to other courses you have taken?

2. How did the collaborative nature of the course influence your learning?
    a. Specifically, you worked as a team, and the results were dependent on working together by dividing up the sequencing experiment in stages, with the success of each stage dependent on the other. Did this setup influence your learning?
3. Did you gain a deeper understanding/appreciation of collaborative practices because of the course?
4. This course emphasizes hands-on and peer-mentored learning rather than instructor-based learning. How did this contribute to your overall experience in the course?
5. How did you find the mentorship experience? What were the associated challenges?
6. In the LS 187C course, students are required to meet with the instructors once a week in a troubleshooting/course planning and development meeting. Can you comment on that experience?

Intellectual Development/Science Awareness, Competence and Engagement (~10 minutes)

1. Please comment on your understanding of genomic biology.
    a. Has the course raised your level of awareness?
    b. Has it deepened the theoretical understanding you've gained from this and other courses?
2. How has this course influenced your perception of scientific research and how scientific progress is made?
3. How has your thinking about your own field of study been influenced by this course?
4. Tell us about any impact this course has had on your ability to learn or to solve intellectual problems.
5. Thinking specifically of learning, how much do you think you have learned in this course compared to other courses you have taken in terms of
    a. subject content
    b. understanding the collaborative nature of science
    c. understanding of the larger context of research
    d. ability to communicate your understanding of science

Research and Teaching Skills/Intellectual Self-Confidence (~10 minutes)

1. Has this course made you more confident about your research skills?
2. This course was designed, in part, because of the growing emphasis on computer-based analysis of raw data, such as analysis of sequencing gels with the eseq program. This is a skill that colleges and universities are only beginning to teach. Do you feel that this course effectively developed those skills?

3. As in most research labs, a significant part of the experience is studying the scientific literature and presenting findings to one's colleagues. Has this course given you a new skill in this area of expertise?
4. Did the fact that you were doing real scientific research as part of this course influence you? Would the class be just as effective with "canned" labs in which the outcome is known?
5. Did your experiences in this course help to develop your troubleshooting skills?

E. Other Questions? (~5 minutes)

1. This class is unusual in that it is an ongoing research project. Are you interested in the future of this class any more than any other class you have taken in the past because of this?
2. Is there anything else we haven't already talked about that you feel you have gained from this class?
3. Overall, what do you see as the successful outcomes of the course?
4. What do you see as the challenges/problems of the course?
5. What might you add or change about the course if it was to be taught again in the future?

Closing

A. Before we end, does anyone have anything to add?

B. Any questions?

C. If anyone does have anything they would like to add, feel free to email either one of us.

D. Thank you for your time and your thoughts on this course. Your comments will be helpful to future course development.

APPENDIX C
Faculty Interview Protocol

Introduction

A. Greeting
B. Logistics
   1. Conversation will be audio taped
   2. Conversation will be relaxed
   3. Conversation should last about one hour
C. Purpose of interview – to understand the challenges and rewards associated with teaching a course using research

Logistics

A. What was the specific role that you played in the lab?
B. What were the course objectives?
C. Can you explain to us what you did each week? Week 1, Week 2, etc.
D. Can you explain to us the student reaction each week? Week 1, Week 2, etc.

Motivation and Goals and Implications

A. Do you believe the experience of doing real research as opposed to a more typical lab exercise engaged your students more deeply?
B. Did participating in the research project help to foster a sense of collaboration or community among your students?

Learning

A. How do you think the research experience has affected the students' understanding of science?
B. How do you think the experience has affected the students' analytic and research skills?
C. How do you think the course has affected the students' self-confidence (before and after the course) about research/genomic biology?
D. How do you think the course has affected the students' research aspirations/attitude toward research?

Other Questions?

A. What do you see as successful outcomes of this interaction among courses?
B. What were the challenges?

Closing

A. Any questions?
B. Any additional comments?
C. Thanks for your time!