20.020 Introduction to Biological Engineering Design
Spring 2009

A Pilot Study of Curriculum Innovations Implemented in a New Project-Based Subject, Introduction to Biological Engineering Design (20.020)

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Assessment Summary

A Pilot Study of Curriculum Innovations Implemented in a New Project-Based Subject, Introduction to Biological Engineering Design (20.020)

Introduction to Biological Engineering Design is a new subject that provides a project-based introduction to the engineering of synthetic biological systems. Throughout the term, students develop projects that are responsive to real-world problems of their choosing, and whose solutions depend on biological technologies. Lectures, discussions, and studio exercises introduce (1) components and control of prokaryotic and eukaryotic behavior, (2) DNA synthesis, standards, and abstraction in biological engineering, and (3) issues of human practice, including biological safety; security; ownership, sharing, and innovation; and ethics.

In fall, 2008, Drs Natalie Kuldell and Drew Endy sought guidance from the Teaching and Learning Laboratory in conducting a preliminary study of their initial implementation of 20.020. The primary assessment methodology was a survey administered online at the end of the Spring '08 semester. The survey consists of multiple choice questions, rating scales, and short answer open-ended questions. Survey topics include class activities, higher order learning, team dynamics, critical moments in the 20.020 learning experience, position on several bio-engineering issues, and shifts in major.

Fourteen students took the 20.020 post survey: twelve freshmen, one sophomore, and one junior. Freshmen received preference in class enrollment.

Findings[1]

Overall, respondents rated the 20.020 experience highly.

Students' responses about their learning experience, learning behavior, team experience, team's cognitive behavior, and biomedical beliefs profile 20.020 as an effective, positive learning environment that made an impact. Their comments to the open-ended questions illustrate their appreciation for the effort of Drs. Kuldell and Endy.

As a result of 20.020, students changed their thinking about their major.

Eleven of the 14 respondents became more confident about their choice, while three become less confident. Eleven students stated 20.020 increased their interest in biological engineering.

Students found eight of the nine core learning experiences of value.

They viewed most positively choosing a project of interest to them, working with more senior students, learning through a project-based class, and working with other 20.020 students. They also found giving presentations and learning through active/challenge based lectures worthwhile. They were neutral toward assigned readings and homework questions.

Higher order thinking characterizes how students learned in 20.020.

The class activities stimulated students to reflect on relationships among concepts, use analogies to deepen understanding, and think about how concepts could be applied to other situations. In addition, the group work placed them in situations which required them to explain concepts or make cogent arguments to persuade others.

Every respondent found working on a team a very positive learning experience.

Twelve of thirteen respondents "strongly agreed" that the team experience was positive. Everyone thought the other members of his/her team worked well together. Almost all thought the other team members were motivated and contributed in a meaningful way.

It is important to note that the positive team spirit was not the result of the absence of conflict or differences of opinion; rather, a team spirit emerged as the result of the willingness of team members to compromise when different positions surfaced. Students often listed "compromise" as a strategy used to help their group evolve into a team. Their open-ended comments suggest they have an understanding of the dynamics involved in effective compromise.

Senior students as advisors to the teams added to the effectiveness of the 20.020 learning experience.

Students appreciated the role the senior students played. They described the work of the senior advisors as "extremely helpful," "super," "making a significant contribution."

By working together on a number of in-class activities, members of a team developed a shared conceptual framework that helped them collectively to reason through their class project.

The smaller in-class projects helped members of a team collectively to formulate mental models of mechanisms and design principles, to struggle as a team with problematic aspects of the activities, and to acquire similar understandings of conceptual content. Such shared understandings and common experiences shaped how a team thought about its major project.

Several hypotheses about project-based learning curricula emerged that would be of value for future studies to explore in the context of freshmen project-based classes, even though variants of these hypotheses have been explored in other educational settings.

1) A group is more likely to evolve into an effective team if its members perceive the projects as meaningful.

2) Empowering students with choices and instilling them with the sense they can do something of value contributes to teams' bonding.

3) If team members worked previously together on smaller projects that require higher order thinking, the team is more likely to acquire a shared conceptual framework that will shape how they reason through a major class project

4) In order for a project-based learning curricula to have a significant impact, the projects must stimulate higher-order thinking.

5) Projects that stimulate higher-order thinking are likely to increase how well/positive students relate to the subject.

[1]Although the data are positive, one should be cautious about generalizing from the results given the small sample size.

A Pilot Study of Curriculum Innovations Implemented in a New Project-Based Subject, Introduction to Biological Engineering Design (20.020)

Introduction to Biological Engineering Design is a new subject that provides a project-based introduction to the engineering of synthetic biological systems. Throughout the term, students develop projects that are responsive to real-world problems of their choosing, and whose solutions depend on biological technologies. Lectures, discussions, and studio exercises will introduce (1) components and control of prokaryotic and eukaryotic behavior, (2) DNA synthesis, standards, and abstraction in biological engineering, and (3) issues of human practice, including biological safety; security; ownership, sharing, and innovation; and ethics.

In fall, 2008, Drs Natalie Kuldell and Drew Endy sought guidance from the Teaching and Learning Laboratory in conducting a preliminary study of their initial implementation of 2.020. The primary assessment methodology was a survey administered online at the end of the Spring '08 semester. The survey consists of multiple choice questions, rating scales, and short answer open-ended questions. Survey topics include class activities, higher order learning, team dynamics, critical moments in the 20.020 learning experience, position on several bio-engineering issues, and shifts in major.

Fourteen students took the 20.020 post survey: twelve freshmen, one sophomore, and one junior. Freshmen received preference in class enrollment.

Results

Respondents related positively to the 20.020 experience and appreciated the efforts of Drs. Kuldell and Endy. In response to the survey's last questions, "Anything else you'd like us to know," students took the opportunity to thank Drew and Natalie for "a great course," "a good semester," and "a class that was really, really good overall." The following comment sums up well how students view 20.020.

Student quotes removed for OCW to protect anonymity.

In the subsections that follow, the data reveal the effectiveness of the 20.020 experience and illustrate how the instructors managed to create such a positive learning environment. The appendix includes all survey responses. See Tables A - H in the appendix for responses to closed-ended profile questions and Tables I - Y for responses to open-ended profile questions.

Although the data are positive, one should be cautioned about generalizing from the results given the small sample size.

Student Profile

Respondents included eight biological engineering majors, three biology majors, two EECS majors, and one nuclear engineering major. They all reported that 20.020 changed their thinking about their major. Eleven were more confident in their choice, while three were less. As for biological engineering as a major, eleven students indicated that as a result of 20.020 they became more interested in biological engineering as a major. The increased enthusiasm is reflected by several open-ended comments.

Student quotes removed for OCW to protect anonymity.

In terms of previous classes that were especially helpful for 20.020, eight students identified high school biology or related courses. Similarly, they (9) thought their MIT biology or neuroscience course (1) was of value.

Learning Experience (Table 1)

Students rated highly eight of the nine learning experiences. They viewed most positively choosing a project of interest to them, working with more senior students, learning through a project-based class, and working with other 20.020 students. They also found giving presentations and learning through active/challenge based lectures worthwhile. Although eight students viewed favorably hearing presentations, three did not. The one area where students were neutral was the "bio/engineering/teamwork assigned readings/homework questions."

For several of the students, the meaningfulness of the projects and feeling empowered that they could do important work were hallmarks of the 20.020 experience.

Student quotes removed for OCW to protect anonymity.

Table 1 Learning Experiences

	no value	little value	neutral	worthwhile	made a big difference to me	Total
II.1.a. Learning Through A Project Based Class	0 0%	0 0%	0 0%	6 46.2%	7 53.8%	13 100.0%
II.1.b. Learning Through Activity/Challenge Based Lectures	0 0%	0 0%	2 15.4%	9 69.2%	2 15.4%	13 100.0%
II.1.c. Choosing A Project Of Interest To Me	0 0%	0 0%	0 0%	3 23.1%	10 76.9%	13 100.0%
II.1.d. Working With Other 20.020 Students	0 0%	0 0%	0 0%	8 61.5%	5 38.5%	13 100.0%
II.1.e. Working With More	0	0	1	4	8	13

Senior Students	0%	0%	7.7%	30.8%	61.5%	100.0%
II.1.f. In Class Challenges To Teach	0 0%	2 15.4%	4 30.8%	5 38.5%	2 15.4%	13 100.0%
II.1.g. Bio/Engineering/Teamwork Assigned Readings or Homework Questions	0 0%	1 8.3%	8 66.7%	3 25.0%	0 0%	12 100.0%
II.1.h. Giving Presentations	0 0%	1 7.7%	2 15.4%	5 38.5%	5 38.5%	13 100.0%
II.1.i. Hearing Presentations	0	3	2	7	1	13

Learning Behavior (Table 2)

Learning behavior refers to the cognitive behaviors that learners draw upon to acquire knowledge, skills, and understanding. The survey asked students to rate different phrases that describe behaviors representative of higher order thinking in learning. Exploring the degree to which higher order thinking is present in learning is of value because the level of thinking present in students' learning determines how well they are able to understand complex subject matter, can problem solve, apply new knowledge to unfamiliar situations, and formulate viable designs. Examples of higher order thinking include thinking about the relationships among concepts, reflecting on how concepts could be applied to other situations, or using analogies to understand how an unfamiliar mechanism works.

Students reported that all the higher order thinking behaviors listed in the survey were descriptive of their thinking and interactions in 20.020. They rated most positively four cognitive activities: explaining relevant concepts to other students, making a cogent argument to persuade others, thinking about how concepts could be applied to other situations, and reflecting on relationships among concepts. They also rated positively using analogies and thinking about how the in-class activities relate to material previously learned. They were divided on integrating concepts introduced at different times during the term: seven positive and six neutral.

Table 2 Learning Behaviors

	Not at all. I never did this	Low but not zero rating for this statement	Neutral	Somewhat positive rating for this statement	Yes, I did this a lot	Total
II.2.a. Trail & Error Strategies to Problem Solve	1 7.7%	2 15.4%	1 7.7%	5 38.5%	4 30.8%	13 100.0%
II.2.b. Reflecting On Relationships Among Concepts	0 0%	0 .0%	2 15.4%	8 61.5%	3 23.1%	13 100.0%
II.2.c. Explaining Relevant Concepts To Other Students	0 0%	0 0%	1 7.7%	3 23.1%	9 69.2%	13 100.0%
II.2.d. Thinking About How The In-Class Activities Relate To Material Previously Learned	0 0%	1 7.7%	3 23.1%	7 53.8%	2 15.4%	13 100.0%
II.2.e. Making A Cognent Arugment To Persuade Other Students On My Team About Which Strategy/Positions To Adopt	0 0%	0 0%	1 7.7%	6 46.2%	6 46.2%	13 100.0%
II.2.f. Thinking About How Concepts In 20.020 Could Be Applied To Other Situations	0 0%	0 0%	1 7.7%	7 53.8%	5 38.5%	13 100.0%
II.2.g. Integrating Concepts Introduced At Different Times During The Term	0 0%	0 0%	6 46.2%	3 23.1%	4 30.8%	13 100.0%
II.2.h. Using Analogies To Understand	0 0%	1 7.7%	3 23.1%	4 30.8%	5 38.5%	13 100.0%

Team Experience (Table 3)

Students "strongly agree" that working on a team was a positive learning experience. They reported that members of their teams worked well together, were motivated, and contributed in a meaningful way. They were equally enthusiastic about working with senior mentors.

The open-ended responses re-enforce the effectiveness of teams. No respondent identified his/her team as ineffective or dysfunctional. Students' comments suggest three factors that may have played a role in the success of the teams: team members connecting with one another, resolving differences and compromising, and, receiving support from senior students.

In some cases, students connected with other team members simply by working together toward a common goal, e.g., working on presentations; for others, there was a connection from the start. Their comments suggest that working on teams lead to new friendships, excitement about the projects, and a collective sense of making something happen.

Student quotes removed for OCW to protect anonymity.

The effectiveness of the teams appears to have occurred, in part, not because the they did not experience conflict or differences of opinions, but because they did and were able to overcome them through compromise. When asked to identify strategies used to develop their team, respondents often commented about compromise.

Student quotes removed for OCW to protect anonymity.

When asked to list one thing that really resonated with them from class, several students identified compromise.

Student quotes removed for OCW to protect anonymity.

Students not only connected well with one another within teams, they also related well to the senior students assigned to each team as advisors. Students were most appreciative and respectful of the advisory role that the senior students played.

Student quotes removed for OCW to protect anonymity.

Table 3 Team Experience

	Not at all I completely disagree	Low but not zero	Neutral	Somewhat positive rating	Yes, I strongly agree	Total
II.9.a. Members Of My Team Worked Well Together	0 0%	0 0%	0 0%	6 46.2%	7 53.8%	13 100.0%
II.9.b. Everyone On My Team Contributed In A Meaningful Way	0 0%	0 0%	1 7.7%	7 53.8%	5 38.5%	13 100.0%
II.9.c. Everyone On My Team Was Motivated	0 0%	0 0%	2 15.4%	8 61.5%	3 23.1%	13 100.0%
II.9.d. Working On A Team Was A Positive Learning Experience	0 0%	0 0%	0 0%	1 7.7%	12 92.3%	13 100.0%
II.9.3. Working with The Senior Mentors Was A Positive Learning Experience	0 0%	0 0%	1 7.7%	3 23.1%	9 69.2%	13 100.0%

Cognitive Profile of Teams

The "cognitive profile of teams" refers to the collective thinking, shared conceptual perspectives, or shared cognitive experiences of a group. Student responses to the open-ended questions provide examples of a team's collective sense of discovery, its realization of the need to narrow the focus in order to develop an effective design, and its formulation of conceptual frameworks gained from in-class experiences.

When asked to *describe an incident that you remember significantly affecting the development of your project,* several respondents gave examples of their team's sense of discovery, a moment when the group collectively changed its perspective about a problem.

Student quotes removed for OCW to protect anonymity.

Several other responses to the same question relate to the importance of focus; students describe their team's realization of the need to collectively focus effort, limit the project's scope, and think realistically about the proposed design.

Student quotes removed for OCW to protect anonymity.

Students were asked to describe their favorite in class challenge; these were team tasks whose completion required higher level thinking. Their comments illustrate that by having members of a team work together on in-class activities, they formulated a shared conceptual framework that guided the development of their class project.

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Student Beliefs (Table 4)

Students were asked their position on four biological engineering issues. For three of the questions respondents, they were split on their positions: In my lifetime, organisms will be designed entirely on compute. Pond scum works better than any human-designed light-to-energy converter. And, when a biotech company invests in research, they should be able to patent the natural and useful DNA sequences they find. Regarding the forth issue, six of the respondents

believed that the DNA sequences for human pathogens that are available online should not, while four believed they should. By the end of the term, three students who had supported at the start of term having the DNA sequences for human pathogens online no longer did.

Table 4 Student Beliefs

	Yes, my belief has changed (I used to think this was possible and now I don't)	Yes, my belief has changed (I used to think this wasn't possible and now I do)	No, my belief hasn't changed (I thought it was possible and still do)	No, my belief hasn't changed (I didn't think it possible and I still don't)
III.4. In My Lifetime, Organisms Will Be Designed Entirely On Computer	0 0%	0 0%	6 54.5%	5 45.5%

	Yes, my belief has changed (I used to agree with this statement but now I don't)	Yes, my belief has changed (I used to disagree with this statement but now I agree)	No, my belief hasn't changed (I agreed at the start of the term and I still agree)	No, my belief hasn't changed (I disagreed at the start of the term and I still disagree)
III.6. Pond Scum Works Better Than Any Human-Designed Light-To-Energy Converter	0 0%	0 0%	5 50.0%	5 50.0%
III.8. When A Biotech Company Invests In Research, They Should Be Able To Patent The Natural And Useful DNA Sequences They Find	0 0%	1 10.0%	4 40.0%	5 50.0%

	Yes, my belief has changed (I used to think they should be available on line but now I don't)	Yes, my belief has changed (I used to think they should NOT be available on line but now I do)	No, my belief hasn't changed (I thought they should be available on line and I still do)	No, my belief hasn't changed (I thought they should NOT be available on line and I still think they should not)
III.10. The DNA Sequences For Human Pathogens Are Available Online. Should They Be?	3 30.0%	0 0%	4 40.0%	3 30.0%

Findings[1]

Overall, respondents rated the 20.020 experience highly.

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4) In order for a project-based learning curricula to have a significant impact, the projects must stimulate higher-order thinking.

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Appendix

Tables of Results for All 20.020 Post Survey Questions

Closed-Ended Questions: Tables A - H
Open-Ended Questions

Appendix A

Table A Class Status

	Frequency	Percent
First-year student	12	85.7
Junior	1	7.1
Sophomore	1	7.1
Total	14	100.0

Table B Likely Major

	Frequency	Percent
Biological Engineering	8	57.1
Biology	3	21.4
EECS	2	14.3
Nuclear Engineering	1	7.1
Total	14	100.0

Table C Has 20.020 Changed Your Thinking About Your Major?

	Frequency	Percent
Yes, I'm now more confident in my choice	11	78.6
Yes, I'm now less confident in my choice	3	21.4
No, 20.020 didn't factor in my thinking	0	0
Total	14	100.0

Table D Has 20.020 Changed Your Thinking About Biological Engineering As A Major?

	Frequency	Percent
Yes, I wasn't interested before and now I am	0	0
Yes, I was interested before and now I'm not	0	0
Yes, I was a little interested before and now I'm MORE interested	9	64.3
Yes, I was a little interested before and now I'm LESS interested	2	14.3
No, it hasn't changed my thinking about biological engineering as a major (I was interested at start of term and I'm just as interested now)	3	21.4
No, it hasn't changed my thinking about biological engineering as a major (I wasn't interested at start of term and I'm still not)	0	0
Total	14	100.0

Table E Learning Experiences

	no value	little value	neutral	worthwhile	made a big difference to me	Total
II.1.a. Learning Through A Project Based Class	0	0	0	6	7	13
	0%	0%	0%	46.2%	53.8%	100.0%
II.1.b. Learning Through Activity/Challenge Based Lectures	0	0	2	9	2	13
	0%	0%	15.4%	69.2%	15.4%	100.0%
II.1.c. Choosing A Project Of Interest To Me	0	0	0	3	10	13
	0%	0%	0%	23.1%	76.9%	100.0%
II.1.d. Working With Other 20.020 Students	0	0	0	8	5	13
	0%	0%	0%	61.5%	38.5%	100.0%
II.1.e. Working With More Senior Students	0	0	1	4	8	13
	0%	0%	7.7%	30.8%	61.5%	100.0%
II.1.f. In Class Challenges To Teach	0	2	4	5	2	13
	0%	15.4%	30.8%	38.5%	15.4%	100.0%
II.1.g. Bio/Engineering/Teamwork Assigned Readings/Homework Questions	0	1	8	3	0	12
	0%	8.3%	66.7%	25.0%	0%	100.0%
II.1.h. Giving Presentations	0	1	2	5	5	13
	0%	7.7%	15.4%	38.5%	38.5%	100.0%
II.1.i. Hearing Presentations	0	3	2	7	1	13
	0%	23.1%	15.4%	53.8%	7.7%	100.0%

Table F Learning Behaviors

	Not at all. I never did this	Low but not zero rating for this statement	Neutral	Somewhat positive rating for this statement	Yes, I did this a lot	Total
II.2.a. Trail & Error Strategies to Problem Solve	1 7.7%	2 15.4%	1 7.7%	5 38.5%	4 30.8%	13 100.0%
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II.2.h. Using Analogies To Understand	0 0%	1 7.7%	3 23.1%	4 30.8%	5 38.5%	13 100.0%

Table G Team Experience

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II.9.a. Members Of My Team Worked Well Together	0	0	0	6	7	13
	0%	0%	0%	46.2%	53.8%	100.0%
II.9.b. Everyone On My Team Contributed In A Meaningful Way	0	0	1	7	5	13
	0%	0%	7.7%	53.8%	38.5%	100.0%
II.9.c. Everyone On My Team Was Motivated	0	0	2	8	3	13
	0%	0%	15.4%	61.5%	23.1%	100.0%
II.9.d. Working On A Team Was A Positive Learning Experience	0	0	0	1	12	13
	0%	0%	0%	7.7%	92.3%	100.0%
II.9.3. Working with The Senior Mentors Was A Positive Learning Experience	0	0	1	3	9	13
	0%	0%	7.7%	23.1%	69.2%	100.0%

Table H Student Beliefs

	Yes, my belief has changed (I used to think this was possible and now I don't)	Yes, my belief has changed (I used to think this wasn't possible and now I do)	No, my belief hasn't changed (I thought it was possible and still do)	No, my belief hasn't changed (I didn't think it possible and I still don't)
III.4. In My Lifetime, Organisms Will Be Designed Entirely On Computer	0 0%	0 0%	6 54.5%	5 45.5%
	Yes, my belief has changed (I used to agree with this statement but now I don't)	**Yes, my belief has changed (I used to disagree with this statement but now I agree)**	**No, my belief hasn't changed (I agreed at the start of the term and I still agree)**	**No, my belief hasn't changed (I disagreed at the start of the term and I still disagree)**
III.6. Pond Scum Works Better Than Any Human-Designed Light-To-Energy Converter	0 0%	0 0%	5 50.0%	5 50.0%
III.8. When A Biotech Company Invests In Research, They Should Be Able To Patent The Natural And Useful DNA Sequences They Find	0 0%	1 10.0%	4 40.0%	5 50.0%
	Yes, my belief has changed (I used to think they should be available on line but now I don't)	**Yes, my belief has changed (I used to think they should NOT be available on line but now I do)**	**No, my belief hasn't changed (I thought they should be available on line and I still do)**	**No, my belief hasn't changed (I thought they should NOT be available on line and I still think they should not)**
III.10. The DNA Sequences For Human Pathogens Are Availabe Online. Should They Be?	3 30.0%	0 0%	4 40.0%	3 30.0%

Appendix B: Recap of Open-Ended Questions

I.2. Did you take a class in high school that you found especially helpful for 20.020?

Summary of Responses:

4 no's
3 biology
2 AP biology
1 biotech research
1 science research
1 biotechnology
1 molecular biology

I.3. Have you taken a class at MIT that has been especially helpful for 20.020?

Summary of responses:

4 No
4 7.13,
1 7.012
1 7.02
3 biology
1 neuroscience

II.3. Critical moment for team project: Describe an incident that you remember significantly affecting the development of your project.

II.4. Critical moment for team building: Describe an incident that you remember as critical for developing your team dynamics.

II.5. Describe your favorite in class challenge and what it meant to your thinking or your team project.

II.6. Triangle: list three things that stick out from class

II.7. Square: List one thing that really squared or resonated with you from the class

II.8. Circle: List a question or questions that are still circling in your mind

II.10. Is there some change to 20.020's format that you'd make? Your feedback here could include class structure (lecture/studio), emphasis of teaching (things to do more or less of next time), workload (in class/outside of class) etc

III.1. At the beginning of the term nearly everyone agreed that "Failure is a natural part of successful engineering. Please describe one example from the term that you think best illustrates this idea OR say that your thinking has changed and you no longer believe the statement above to be true.

III.2. At the start of the term, most people in the class did NOT believe that "understanding = unlimited time + data." Based on your experiences in 20.020 this term, what is missing from this equation (and give one example that leads you to say this) OR say that you now believe this equation to be complete and true.

III.3. At the beginning of the term, most folks felt positive they could "think of 3 ways that might turn a group into a team. Please list three strategies you used this term to develop your project team OR state that you did not find helpful strategies.

III.5. Please list 3 advances that would enable computer-aided design of biological systems.
This is a follow up to the previous multiple choice question: III.4. *At the beginning of the term, we asked if you agreed with this: "The Boeing 777 was the first commercial aircraft to be designed entirely on computer. Wow! In my lifetime, biological engineers will be able to reliably design organisms this way too" Now that you've tried to design an organism, have your feelings about this statement changed?*

III.7. List 3 natural design principles OR 3 human ones that influence your weighing of pond-scum vs man-made light-to- energy converters. This is a follow-up question to the previous multiple-choice question III.6.: *At the beginning of the term we asked if you agreed with this: "pond scum works better than any human-designed light-to-energy converter" Now that you've tried to design an organism, have your feelings about this statement changed?*

III.9. As a follow up to the last question, please list 3 factors that influence your thinking. This is a follow-up question to the previous multiple-choice question, III.8: *The start of the term we asked you: "when a biotech company invests in research, they should be able to patent the natural and useful DNA sequences they find" Has your thinking about this issue changed?)*

III.11. As a follow-up to the last question, please list 3 factors that influence your thinking. Mulitple choice question, III.10: *At the start of the term we noted "the DNA sequences for human pathogens are available online." and asked "Should they be?" Has your thinking about this issue changed over the term?*

III.12. Anything else you'd like us to know?