Teaching for Adaptive Expertise in Biomedical Engineering Ethics

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ABSTRACT: *This paper considers an approach to teaching ethics in bioengineering based on the How People Learn (HPL) framework. Curricula based on this framework have been effective in mathematics and science instruction from the kindergarten to the college levels. This framework is well suited to teaching bioengineering ethics because it helps learners develop "adaptive expertise". Adaptive expertise refers to the ability to use knowledge and experience in a domain to learn in unanticipated situations. It differs from routine expertise, which requires using knowledge appropriately to solve routine problems. Adaptive expertise is an important educational objective for bioengineers because the regulations and knowledge base in the discipline are likely to change significantly over the course of their careers. This study compares the performance of undergraduate bioengineering students who learned about ethics for stem cell research using the HPL method of instruction to the performance of students who learned following a standard lecture sequence. Both groups learned the factual material equally well, but the HPL group was more prepared to act adaptively when presented with a novel situation.*

INTRODUCTION

Adaptive Expertise in Bioengineering Ethics

Developing expertise is a clear goal for education in any domain. Experts can solve problems quickly, apply their understanding in appropriate contexts, and their depth of understanding can make seemingly complex problems tractable.[1] Researchers have identified two kinds of experts: routine experts and adaptive experts.[2] Routine experts

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are technically skilled and very efficient at completing their work in their domain. This type of expertise is important in any field. However, this type of expertise may have a hidden downside. Routine experts may fail to search out new solutions to problems when it is appropriate or fail to notice that a problem is significantly different from problems solved in the past.[3]

Adaptive experts use knowledge flexibly in a new situation to modify existing procedures or invent new ways to approach novel problems.[1,2] This kind of expertise is particularly critical to foster in fields like bioengineering in which the knowledge base changes quickly.[4] Adaptive experts display content knowledge at the same level as routine experts, but also display additional characteristics. These include willingness to employ different representations and methods to solve problems, interest in continuing to learn during their careers, an ability to monitor their own level of knowledge about a topic, and a view of knowledge as a dynamic rather than static entity.[1,5,6]

The ways to help students develop adaptive expertise are currently under investigation. Even the most advanced biomedical engineering student will probably not become an adaptive expert, or an expert of any sort, during his or her undergraduate years. Consequently, curriculum designers need to consider the types of learning experiences that will be most likely to lead students to develop into adaptive experts during their careers. Curricula to promote the development of adaptive expertise have been studied in various bioengineering content domains.[6-8]

Curricula to develop adaptive expertise in engineering ethics are beginning to be studied.[7] Expertise in problem solving in engineering ethics requires that people apply combined knowledge about the engineering aspects of the problem and about relevant ethical issues to make an acceptable decision.[9] Adaptive expertise in engineering ethics requires making these decisions in new or uncertain situations – for example, when regulations change or new scientific discoveries are made. The characteristics of adaptive expertise that apply in other areas should support successful adaptive performance in engineering ethics as well. The use of multiple methods to solve problems, a view of the engineering ethics domain as an evolving body of knowledge, a willingness to continue to learn in this area, and an understanding of when their knowledge is inadequate will all help students develop adaptive expertise in this area.

The focus of this study was the characteristic of employing multiple methods and representations to solve problems. We expanded this idea for the ethical domain to include consulting multiple stakeholder perspectives. While all of the characteristics of adaptive expertise will be important in developing understanding and skill in making ethical decisions, consulting multiple perspectives is particularly crucial for two reasons. One is that considering and addressing multiple stakeholders' perspectives on an issue is an important part of many engineering ethics curricula.[10-14] This is a step in several guidelines for making ethical decisions.[9,15] Secondly, in engineering ethics, a hallmark of an adaptive approach to a new situation is the act of taking conflicting facts and opinions into account and attempting to make a decision that addresses each perspective. Developing this latter feature of adaptive expertise in students is the primary focus in the present ethics study.

Ethics Education in Biomedical Engineering

One desired outcome of teaching ethics for undergraduate biomedical engineering education is to develop adaptive learning skills in students. There are several possible methods for teaching biomedical engineering ethics in college settings. One method is to engage students in hands-on practice or internships, and another is to lecture. We used a third method, the HPL approach, because we thought it would promote the development of adaptive expertise.

One method for teaching biomedical engineering ethics is to provide extensive hands-on practice in an apprenticeship situation.[16] For example, service learning programs and internships send participants into community settings and workplaces to learn from experience. The goal of these opportunities is for participants to develop hands-on expertise and to accumulate practical experience. In engineering ethics, this teaching method could be implemented through internship experiences. It could also be incorporated into a course. Pedagogical methods that rely only on case studies could fall into this category. This method has much to recommend it. Experts in a field develop skills and heuristics over the course of extended hands-on experience.[17] In addition, these learning opportunities can be very motivating for students.[18] Participants often report that the event was rewarding. However, there are two challenges regarding this approach for undergraduate engineering. One is that in large engineering classes that have significant technical content, extensive hands-on activities can be difficult to implement. In addition, students do not automatically learn what instructors think is important by engaging in these activities.[19] For example, Barron and colleagues[20] asked children to design a school fun fair as a math project. The children were very engaged in the project. However, they spent more time concentrating on how to make attractive booths for the fair rather than thinking about the quantitative issues of feasibility and expense, which were the main learning goals of the experience.

Another way to teach ethics for biomedical engineering students is a lecture-based approach. This commonly practiced approach is efficient, and students often learn factual material quite well with it. It can also provide students a clearer picture of what they are expected to learn and whether they learned it than can extensive hands-on experience without feedback. Nevertheless, it does have drawbacks. Students often learn facts and procedures, but do not know when or how to apply them.[21,22] This does not mean that teachers should never use directed instruction. If students have been prepared to understand the important ideas in a lecture by working through activities that give them a chance to construct their own understanding, they can benefit from materials presented in a lecture format.[23]

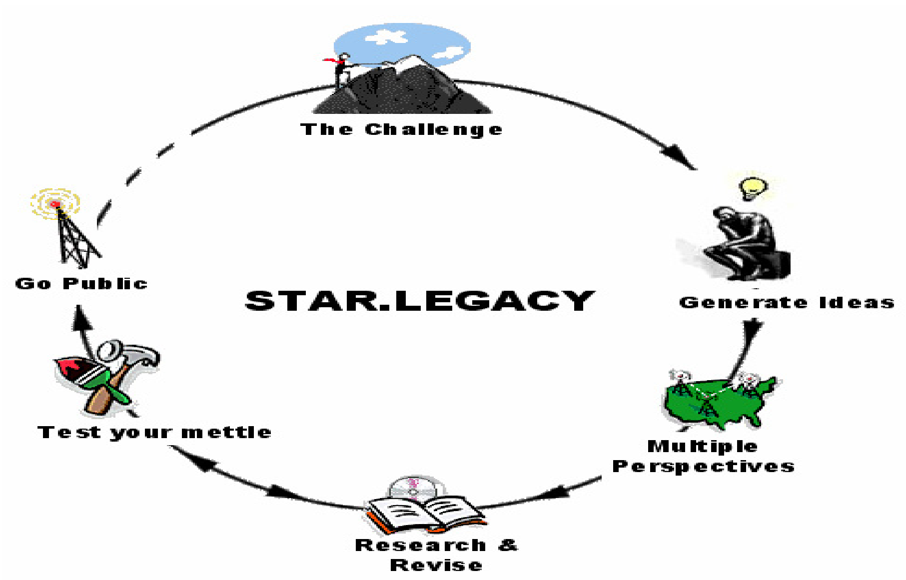
The approach in this work is designed to benefit from student exploration and directed instruction. The “How People Learn” (HPL) approach follows principles of designing effective learning environments gleaned from educational research.[1] An HPL learning environment is student centered, knowledge centered, assessment centered, and community centered. A student-centered learning environment uses students’ current capabilities as a starting point for learning. A knowledge-centered learning environment focuses teaching on the important content in the domain and on achieving mastery in the content area. An assessment-centered learning environment builds in opportunities for students and teachers to acquire feedback on students' progress throughout the learning process. A community-centered learning environment is appropriate to the community context. Instructional designers have followed these principles to create effective curricula in such diverse areas as elementary mathematics,[20] statistics,[24] and biomechanics.[8] In addition to improving learning of factual material, these curricula lead students to outperform students who learned in traditional lecture formats on adaptive expertise.[24] Following these principles allows instructional designers to capitalize on the benefits of both lecture and hands-on practice.

In this work, we implemented the HPL framework with the technology of the STAR.Legacy (SL) cycle (see Figure 1).[25] This cycle is a template for instructional design that is based on the findings of learning science research. One important finding is that case-based learning can be beneficial in practical fields that require the mastery of significant amounts of factual information, such as law and medicine.[26] For this reason, challenge cases are the motivating or anchoring activity in the SL Cycle. Another finding is that students learn more when they generate ideas and attempt to solve problems prior to consulting resources and hearing expert opinions.[23,24] The SL Cycle gives students the opportunity to generate their own ideas and solutions before they consult resources. Another important finding is that giving students formative feedback and having them revise their work in light of that feedback can improve learning.[27] The SL Cycle includes opportunities for feedback and revision. Finally, the necessity of creating an authentic final product is motivating for students and allows them to practice applying what they have learned to a realistic situation they could face in an actual career setting.[20] Thus, the SL Cycle concludes with an opportunity to create an authentic product.

The VaNTH (Vanderbilt, Northwestern, University of Texas, and Harvard/MIT) National Science Foundation (NSF) Engineering Research Center (ERC) in Bioengineering Educational Technologies has used the HPL framework to design effective and efficient instructional materials in several areas of bioengineering including biomechanics, biotransport, biotechnology, physiology, and optics.[7] The project has also created taxonomies of the core ideas and subject areas in bioengineering.[28] These areas include many knowledge domains in addition to ethics. To date, VaNTH researchers have developed several HPL learning modules and courses in many of the domains, including ethics (but see [29-31]). VaNTH research has shown that the HPL framework is effective in bioengineering education for developing both factual knowledge and adaptive expertise.[7] Ethics instruction differs in some aspects from these more technical content areas, so it is an open question as to whether HPL is an effective framework for crafting this sort of instruction.

We hypothesized that HPL would be effective because it builds in opportunities to learn for adaptive expertise. Schwartz and colleagues[32] distinguish between learning experiences that promote efficiency and those that promote innovation. To develop adaptive expertise requires experiences that promote both outcomes. Schwartz and colleagues describe an Optimal Adaptability Corridor (OAC) that leads to adaptive expertise. HPL is a type of learning experience that can lead students through this OAC. In engineering ethics, HPL can do this by providing experiences that help students develop into efficient problem solvers who can let go of intellectual constraints associated with their old thinking and be innovative when necessary. The different phases of the SL Cycle offer ways to develop efficiency and innovation in engineering ethics. For example, generating ideas about how to tackle an ethics dilemma can lead students to be innovative, while hearing multiple perspectives from experts can help them refine some of their ideas and become more efficient. Doing initial research and attempting to solve ethical dilemmas can lead students to try out innovative solutions. Having a chance to revise those solutions in the face of feedback can help them develop more efficient and accurate approaches to ethical problems. Developing ethical approaches to problematic cases repeatedly in the engineering domain can help students achieve efficiency in solving ethical problems. It seemed likely then, that HPL could develop adaptive expertise in engineering ethics; however, this conjecture was untested. Therefore, one of our main research questions was whether the HPL approach could support the development of adaptive expertise in engineering ethics.

Figure 1. The STAR.Legacy (SL) Cycle



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We drew on the HPL framework to design an instructional module on ethics in stem cell research that is simple to implement, requires the same amount of time as a standard lecture unit, and is learner, knowledge, assessment, and community centered. This stem cell research unit is learner centered because students generate their solutions first, and then find resources and expert solutions. It is knowledge centered because students need to develop knowledge about the content and about ethical principles, guidelines and standards. The unit is assessment centered because it provides opportunities for evaluation of understanding and chances to revise based on those assessments. Finally, the unit is community centered because it focuses on an issue in ethics (stem cell research) that is geared specifically for the bioengineering community.

Research Questions

This study compared the performance of two groups of students: one group learned about stem cell research ethics using a traditional lecture method, and one group learned using the HPL method. The two groups covered the same material in different formats. The traditional group participated in two lectures on stem cell research basics, potential controversies and benefits, and ethical guidelines. They described many of these topics in a summarizing homework assignment. In two class periods and one homework assignment, the HPL group followed the SL Cycle to research stem cell topics, examine multiple perspectives on the issue, and devise a plan to solve an ethical challenge in the area of stem cell research.

Both groups completed a pre- and a post-test that measured factual knowledge and adaptive expertise. The factual items focused on knowledge of stem cell research basics and of regulations on the use of stem cells. The adaptive item asked students to create and justify a plan of action to solve an ethical problem in the context of a change in regulations on stem cell research.

We expected scientific and ethics content knowledge to increase equally for both groups. The lecture group learned content from the two lecture sessions and from answering the questions on their homework assignment. The HPL group learned the content from brief video presentations during the two class sessions and from the research involved in their homework. The prediction of equal factual learning is somewhat counter-intuitive since we devoted more time to direct presentation of factual information for the lecture group than the HPL group.

We hypothesized that the HPL method would be more successful at promoting the development of adaptive expertise than would a standard lecture approach. In the HPL classes, students had the opportunity to actively deal with multiple perspectives. In the lecture classes, the instructor told the students about several perspectives on stem cell research and the evidence and beliefs justifying those perspectives. The HPL group generated multiple points of view, researched the evidence or scientific support for them, and then attempted to integrate these views and conflicting evidence. Therefore, we expected that when asked to develop a plan in a real situation, the HPL group would consider more perspectives in making their decisions than would the lecture group. This capability is vital in a field for which codes of ethics and ethical standards are changing as new scientific discoveries are made. The next generation of biomedical engineers will need to consider different perspectives in order to make good ethical decisions.

METHODS

Participants

Thirty first-year undergraduates (approximately 18-19 years of age) participated in this experiment. Approximately half of the students were randomly assigned to the HPL group and half to the lecture group. Data were collected and analyzed from all of the students who gave signed consent and were present for both classes that constituted the experiment.

Materials

HPL Instructional Method

The HPL instructional module followed the SL Cycle shown in Figure 1. Content for the SL Cycle was delivered via the web.[a] We will describe each step in the module in turn.

The Challenge

The SL Cycle begins with a challenge for students to craft a plan to solve a practical and open-ended problem. Challenges are similar to cases used in case-based learning. While these problems are more in-depth than a typical textbook problem, they are not as in-depth as a research or paper assignment. Challenges have two main benefits; 1) they involve students in cognitive apprenticeship and 2) they provide anchored instruction.[26] In cognitive apprenticeship, students learn concepts and skills in contexts similar to the contexts in which they will use this knowledge in real-life situations. These analogous conditions should increase appropriate transfer of the knowledge.[33] In anchored instruction, students glean information they need to solve a problem from a richly contextualized story, or anchor. This process encourages students to understand the information as a problem-solving tool rather than as a set of unrelated facts.[34] Integrating cognitive apprenticeship and anchored instruction into a case-based learning program provides a format for students to learn skills and knowledge as real-life, problem-solving activities which they will be able to extrapolate and apply to new situations and new problems.

Challenge problems are designed to be difficult to resolve based on only one fact or opinion and to motivate consideration and integration of different information sources. In the Stem Cell Challenge, a U.S. researcher must decide whether to participate with an Australian colleague in replicating results obtained in the Australian lab using human embryonic stem cells (See Appendix A for the full challenge text). There are several issues involved in the challenge that students must discover, learn about, and weigh against one another. These include potential benefits of the research for curing diseases, the legality of using a stem cell sample from another country, and the potential impact on U.S. government funding to the U.S. researcher's lab.

a. A revised version of this module is currently online at http://www.engr.utexas.edu/ethics/modules.cfm.

Generate Ideas

As a first step to solving the challenge, students generate ideas. These ideas include questions about the topic, thoughts about what they need to discover to solve the challenge, and their initial thoughts about the solution. Students generate their own ideas before consulting resources because this activity has been shown to benefit subsequent learning[23] by helping students to understand the nature of the problem they are solving[24] and to find the relevant information in the resources they consult.[34] For example, in a video-based challenge in which middle school students designed a playground, students generated a series of questions about what they would need to know to design the playground. This activity prepared them to identify and use the relevant facts included in the video.[35]

Multiple Perspectives

In the second step, students consult multiple perspectives on the issues involved in the challenge. This activity is a major component of their learning process. In the Stem Cell Challenge, the multiple perspectives component consisted of video clips of scientists, lawyers, and members of the public who had a stake in a particular view on stem cell research. These included a researcher explaining basic scientific concepts in stem cell research, a lawyer discussing legal issues and regulations, a right-to-life activist discussing his viewpoint on stem cell research, and a sufferer from a medical condition that might be improved by stem cell therapy. Viewing these videos can help students answer the questions they generated and become aware of issues or questions they had not considered.[25] This experience can guide their further research process.

Research and Revise

After consulting multiple perspectives, students conduct research on their own using the web and other sources that they identify. This research guides their revision of the initial plan for solving the challenge that they created in the “Generate Ideas” step. The resources students consult and the expert videos they watch in “Multiple Perspectives” provide them with factual information about stem cells, stem cell research potential, and governing regulations.

For the HPL homework assignment, students wrote a plan of action for responding to the challenge and justified their plan from one of five stakeholder perspectives (see Appendix B for homework assignment). The class was divided equally between the following five perspectives: an attorney retained by the lab to advise them on regulatory issues, a Program Director for the National Institute for Neurological Disorders at NIH, a lobbyist for the National Right to Life Organization, a personal friend whose child suffers from multiple sclerosis, and the chief financial officer for the research lab. Focusing on one perspective allowed students to learn the information and opinions associated with that perspective in depth. In addition to an in depth understanding of one stakeholder perspective, this homework assignment required students to gather information on the regulations, potential benefits and risks, and basic scientific facts involved in stem cell research.

Test Your Mettle

Following the homework, students answered multiple-choice questions in the "Test Your Mettle" section of the website. These questions covered scientific and ethical issues about stem cells. Students received immediate corrective feedback on their answers. This feedback informed students about what they had learned so far in the unit. This information could then shape students' actions in subsequent phases of revision and lead to further learning. Formative assessments such as these allow students and teachers to assess progress and adapt their learning strategies during instructional units.[36] Research has demonstrated that formative assessments increase the likelihood that students will revise their work and lead to improved learning.[20] Developing an attitude of "continuous improvement" in learning and in problem solving is an important philosophical component that supports our undergraduate curriculum.

Go Public

In the final part of the Stem Cell Challenge, students met in groups to solve a new challenge and presented their solutions to the class (see Appendix C for Challenge 2). In this second challenge, Congress is considering lifting the 2001 ban on the creation of new stem cell lines, based on findings that showed good results in curing Parkinson's disease using a new technique in stem cell therapy. Students' task is to craft and justify a decision on whether to present findings from "their lab" to Congress that suggest that the new technique may not be safe in the long term. Each group had one member from each of the perspectives from the homework (legal, financial, scientific, moral, and personal). Students were instructed to craft a solution that addressed as many of the perspectives as possible. Their assignment was not to satisfy each person's requirements, but to attempt to take all of these different perspectives into account in developing their consensus plan. The objective of this assignment was to help students further develop an adaptive approach to solving ethical dilemmas. Specifically, this activity should lead them to consider and attempt to reconcile multiple viewpoints on difficult ethical issues.

Lecture Instructional Method

The lecture group did not complete the Stem Cell Challenge. Instead, they heard two lectures that covered the same content on stem cell research that the HPL group had researched and been exposed to. Both groups learned about the ethical issues involved in, regulations on, and scientific information about stem cell research.

Lecture 1 had three sections. The first section addressed general ethical problem solving for engineers. It included general information about why ethics is important in engineering, an heuristic for ethical problem solving for engineers, and a discussion of engineers' responsibility to the public. The second section covered scientific content information on stem cells. This information included a definition of stem cells, how they work, and a discussion of the potential benefits and risks of stem cell research. The third section covered some of the ethical issues and regulations regarding stem cells. These included the current regulations on stem cell research in the US and abroad, viewpoints of those who oppose this research based on their values, and current and past legal decisions involving stem cell research.

Lecture 2 addressed some of the same topics as Lecture 1, but in greater depth. There were three sections in this lecture. The first focused on scientific content. It included a more detailed definition of stem cells, presented the different types of stem cells, and discussed many sources of stem cells. The second section addressed ethical issues. It separated the issues related to adult and embryonic stem cell research, presented four positions on the status of the embryo, covered other ethical issues such as how embryos could be collected, genetic manipulation of stem cells, xenotransplanted stem cells, and parthenogenesis. The third section was a study of a case in which an embryo was implanted by in vitro fertilization to create genetically matched umbilical cord stem cells to save a child in the family who had a rare disorder. The class discussed the ethical issues in this case.

These lectures included the videos from the "Multiple Perspectives" section of the Stem Cell Challenge. The instructor showed the videos when discussing the relevant point in the lecture. The lectures exposed the lecture group to the same information and opinions to which the HPL group had access.

The lecture group's homework was different than the HPL group's. The students completed five short-answer questions on the facts, the ethical principles involved, and the current regulations on stem cell research (See Appendix D for homework assignment). These questions served as a review of the material covered in the lecture and also ensured that the lecture group had covered the same basic concepts about stem cells, potential benefits and risks, and regulations on research that the HPL group addressed in their homework.

Assessments

The pre-and post-test assessed students' factual knowledge about stem cells and stem cell research ethics and their adaptive expertise in making ethical decisions about stem cell research (See Appendix E for test questions). Three short answer questions were used to determine factual knowledge ("What are embryonic stem cells?", "What are the regulations on using stem cells for research in the United States?", and "What are some potential benefits of stem cell research?"). Each of these questions was scored "1" for correct and "0" for incorrect.

The adaptive expertise question posed a novel situation and asked students to create and justify a plan of action. The situation was related to a panel report issued in 2003 indicating that current stem cell lines might be unsuitable for human use.[37] The panel proposed creating new stem cell lines, a move that would require a change in current regulations on stem cell use. The students' instructions were to write a letter to Congress explaining and justifying their decision on the panel's recommendation. This scenario required students to make an ethical decision in a new situation. Students' answers were coded for coherency and accuracy. The possible scores were "0" for little or no answer, "1" for a partially correct answer, and "2" for a reasonable and justified answer. Students' answers were also coded for the extent to which they showed adaptive expertise. A code of "0" meant the student did not consider multiple perspectives in their argument, while a code of "1" indicated that the student did consider multiple perspectives.

Coding schemes were developed for accuracy and adaptiveness for the adaptive expertise question post-hoc. For each item, a primary coder used a subset of the answers to develop a scheme. Once a coding scheme was established, a secondary coder trained on a subset of tests. The primary and secondary coders checked reliability using new tests drawn randomly from the pre- and post-tests. For each of the items, inter-coder agreement was 93% or above. The primary coder subsequently scored all the adaptive expertise questions.

Procedure

Students were randomly assigned to either the HPL or the lecture group prior to the first class period. The groups met in separate classrooms. Both groups completed a pre-test in their regular classroom two weeks before the start of the unit. One question was omitted from this test due to experimenter error. Students completed this question at the start of the first class period. Both groups spent two fifty-minute class periods on their respective activities and completed a homework assignment between the first and second class periods that were one week apart. Finally, both groups completed a post-test as a separate section on the class final exam one week after the second class with the explicit understanding that they would not be graded on that portion of the exam. All students had 20 minutes to complete the post-test questions.

The HPL group completed the Stem Cell Challenge during the two class periods. On Day 1, they first heard the challenge and generated ideas individually ("Generate Ideas"). Then they told the instructor some of their questions about the challenge, and these questions guided the instructor's choice of about six videos (from a total of approximately 25) to show the class ("Multiple Perspectives"). Following the videos, the instructor explained the homework and encouraged students to work with other students in the HPL group on the assignment, but asked them not to talk with students in the lecture group since their homework was different. All videos were available on the Challenge website during the week they worked on the assignment ("Research and Revise"). Students did not receive feedback on their homework assignments other than a completion grade. On Day 2, students answered a series of multiple-choice questions on stem cell research and ethics topics ("Test Your Mettle"). The instructor asked students to raise their hand for each question to indicate their answer and discussed the answers to the questions with the entire class. Next, students divided into groups to work on the new challenge ("Go Public"). Each group consisted of one member from each perspective group from the first challenge. In these small groups, students created a plan for solving the second challenge. Finally, students reported their plan to the class and answered peer questions.

In the lecture group, the instructor presented a lecture created with presentation software and showed related videos in each class period. Lecture 1 covered the basics of stem cells, current directions in stem cell research, and a set of steps to follow when making ethical decisions. The instructor explained each point and showed all of the corresponding "Multiple Perspectives" videos from the HPL materials. The students completed the short-answer homework assignment between the two lectures. They had access to a website with links to the videos shown in class, a list of resources for researching the homework questions, and the professors' lecture during the week they worked on the assignment. Students did not receive feedback on their homework assignments other than a completion grade. Lecture 2 reviewed the definition of stem cells, covered different views on whether they should be created for research, and described a case and explained the decision made in this case and how ethical principles and viewpoints were addressed in the decision.

Design

The design of the study was a 2 x 2 repeated measures design with time as a within-subjects factor (pre-test vs. post-test) and condition as a between-subjects factor (HPL vs. lecture). We used this design to analyze the data for accuracy on the factual and adaptive expertise questions. Additionally, we used a Chi-square analysis to determine the extent of the students' ability to use adaptive expertise in their ethical reasoning.

RESULTS

Factual Questions

The students answered more of the factual questions correctly on the post-test ($\underline{M}$ = 2.76, $\underline{SE}$ = .10) than the pre-test ($\underline{M}$ = 1.69, $\underline{SE}$ = .18), $\underline{F}$ (1, 27) = 29.93, $\underline{MSE}$ = .6, $\underline{p}$ = .00. We used repeated measures ANOVA to analyze these data.[b] The HPL group ($\underline{M}$ = 2.13, $\underline{SE}$ = .14) performed similarly to the control group ($\underline{M}$ = 2.32, $\underline{SE}$ = .15) overall; there was no main effect of group, $\underline{F}$ (1, 27) = .86, $\underline{MSE}$ = .6, $\underline{p}$ = .36. The groups' progress over time was very similar; there was no interaction between time and group, $\underline{F}$ (1, 27) = 0.0, $\underline{MSE}$ = .56, $\underline{p}$ = .99 (See Figure 2).

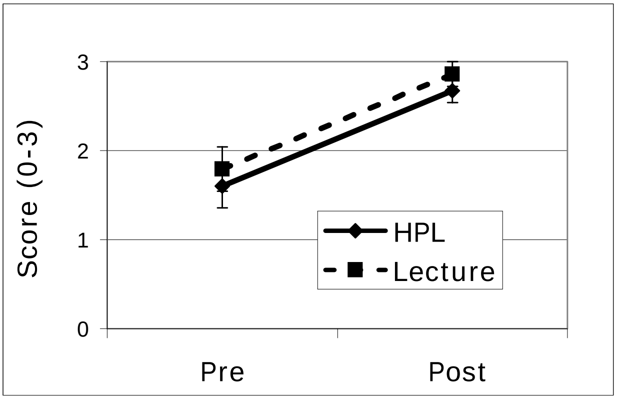

Figure 2*. Results on factual questions*

Factual scores ranged from 0 to 3 questions correct. HPL and lecture students improved from the pre- to the post-test. There was no significant difference in the amount of improvement between the groups.

b. While these are interval data, it is possible that the full set of assumptions for ANOVA are not met by this dataset. Though ANOVA is robust to many violations of assumptions,[38] we wanted to be sure these analyses were valid. To check, we ran a categorical analysis with the same factors using repeated measures logistic regression models (the SAS procedure GENMOD). The results were the same.

Ethical Decision Accuracy

To analyze the data for ethical decision accuracy, we used repeated measures logistic regression models (the SAS procedure GENMOD). The students constructed better ethical arguments on the post-test (M = 1.96, SE = .04) than on the pre-test (M = 1.56, SE = .15), χ^2 (1, N = 30) = 16.9, $p < .001$. The HPL group (M = 1.77, SE = .11) performed similarly to the control group (M = 1.75, SE = .10) overall; there was no main effect of group, χ^2 (1, N = 30) = 0.15, p = .69. The groups also improved similarly; there was no interaction between time and group; adding interaction terms to the model provided no additional explanation of variance. (See Figure 3)

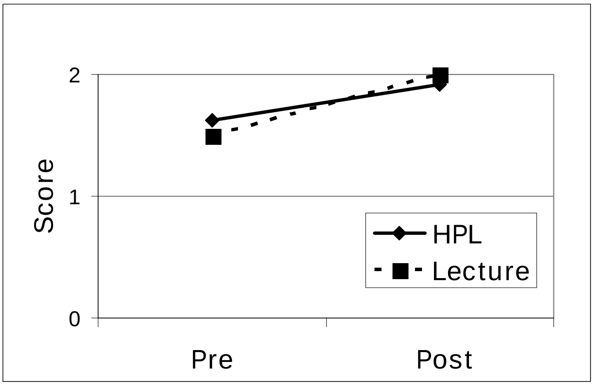

Figure 3*. Results for accuracy on the ethical decision*

Accuracy scores on the ethical decision ranged from 0 to 2. A student received a "0" for little or no answer, a "1" for a partially correct answer, and a "2" for a reasonable and justified answer. HPL and lecture students improved from the pre- to the post-test. There was no significant difference in the amount of improvement between the groups.

Adaptive Expertise

On the adaptive expertise question, approximately the same percentage of students incorporated multiple perspectives in their arguments in the HPL (25%) and control groups (23%) on the pre-test, $\chi^{\square}$ (1, N = 25) = .01, p = .91. In contrast, more of the HPL students (73%) incorporated multiple perspectives in their arguments on the post-test than the control students (33%), $\chi^{\square}$ (1, N = 30) = 4.82, p = .03 (See Figure 4).

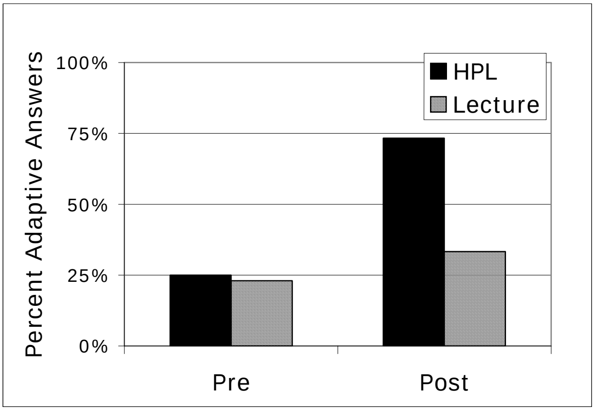

Figure 4*. Results for adaptive expertise on the ethical decision*

For the adaptive expertise score, a code of "0" meant the student did not consider multiple perspectives in their argument, while a code of "1" indicated that the student did consider multiple perspectives. The graph shows the percentage of students in each group who gave adaptive answers on the pre- and post-tests. There was no difference between the groups at pre-test, but the HPL students were more likely to give adaptive answers on the post-test.

Crosstalk

To determine that the two groups acted independently, all students identified those with whom they spoke about class assignments and/or activities between the two class periods. Significant cross-condition discussion could compromise the conclusions of the study. If students in the two groups talked extensively with one another, it could compromise the uniqueness of the treatments. The results demonstrated that there was very little crosstalk (see Table 1). This finding supports the view that the observed differences in adaptive expertise were due to the different instructional treatments provided. It is interesting to note as well that the HPL students talked to each other more than the students in the lecture group did. This suggests that the students found working together valuable for their work.

***Table 1**. Crosstalk Results: "List the people you talked to about your assignment or the class activities."*

Talked to:	No One	Own Group	Opposite Group	No Answer
HPL Group N = 15	21%	79%	0%	7%
Lecture Group N = 15	57%	36%	7%	7%

GENERAL DISCUSSION

The results demonstrate that both instructional methods increased factual understanding, whereas only the HPL method led to a higher level of adaptive expertise in making ethical decisions in a biomedical engineering context. Both groups increased significantly in their factual knowledge about stem cell research and regulations and could give a reasonable answer when asked to evaluate a proposal to change current stem cell regulations. However, the HPL group addressed the perspectives of more stakeholders in their plans. In the real world, these future engineers will need to be able to adapt in new situations as science, society, and regulations change. A more adaptive approach will help them in their careers.

These results support our initial hypothesis that the HPL method should contribute to the development of adaptive expertise more than a standard lecture-based approach. Specifically, we believe the process of generating and revising ideas and solutions led to more flexible adaptive understanding than directly telling the students about ethical decision-making.

One goal of this research was to explore the nature of adaptive expertise in biomedical engineering ethics and how it could be developed effectively. To our knowledge, ideas about adaptive expertise had not been applied to engineering ethics prior to this study. We examined one facet of adaptive expertise, the ability to take multiple perspectives. We adapted this idea to the ethics context by defining it as the tendency to consult and attempt to reconcile different stakeholder perspectives when making ethical decisions in novel contexts. Results indicate that the HPL curriculum advanced this ability.

A second goal of this study was to explore an approach to developing deep understanding that is practical for the large class settings present in many undergraduate engineering courses. The assumption is sometimes made that significant one-on-one time with instructors is necessary to use student-centered approaches to learning that help develop deep understanding. While we do not want to detract from the value of small classes and attention from the instructor, we desire to contribute to the possible ways of achieving similar benefits under less constrained and resource intensive conditions. The Stem Cell Challenge required extensive planning time, but did not require more instructional time than the lecture condition.

Next Steps

The conclusions of this study are limited, as they have not been replicated. However, we are pursuing replication using this module with new student populations at other universities and anticipate similar results in these efforts. In addition, we are creating additional modules for bioengineering ethics that address topics such as the issues surrounding human subject regulations, enabling further comparison of the HPL method to the standard lecture method of instruction in diverse areas. These efforts will advance the investigation of the generality of the benefits of HPL for ethics instruction.

Researchers need a broader conceptualization of adaptive expertise for areas like ethics.[7] This study tested one aspect of a concept of adaptive expertise – the tendency to consult multiple stakeholders and address their needs and views in the course of making a decision. Other facets of adaptive expertise in engineering ethics should also be addressed. One important consideration is the degree to which engineers appropriately use content knowledge to inform their ethical decision-making in new situations.[3] Another important area for further research is how engineers develop dispositions toward adaptive expertise such as considering alternate solutions to problems, viewing knowledge as constantly evolving and learning as a life-long process, and monitoring their own level of understanding.[1,6]

Finally, the students in this study are at the start of their path of development of adaptive expertise in biomedical engineering. It is important to examine how classroom experiences relate to later job performance. Will biomedical engineers trained with an HPL ethics approach exhibit adaptive expertise when they make ethical decisions at work? We plan to measure this and related issues as our students graduate and enter the work force.

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Appendix A: Challenge 1

A colleague of yours, Dr. Green, who is the director of a privately managed biomedical research laboratory in Washington DC, has contacted you for advice on a recent ethical dilemma that has arisen in her lab.

Her lab is regarded as the international leader in neurological research to help cure sufferers of Parkinson's, Alzheimer's, and other neurological diseases and traumas. The lab is primarily funded through NIH grants.

The lab of her long-time collaborator, Dr. Diggity in Melbourne, Australia was awarded a large grant from the Australian government to perform research on nerve regeneration using human embryonic stem cells. Their initial results show a tripling in the survival rate for severe spinal cord injuries, but they have also come under scrutiny from doctors who believe that their methods and equipment are too inadequate to produce repeatable results.

Because Dr. Green's facilities are the only ones capable of making the measurements with the necessary precision, Dr. Diggity suggested that he send the cell samples to Washington. Here the experiment could be duplicated and results confirmed.

Dr. Green needs to decide whether to refuse or accept the invitation to participate with Dr. Diggity.

Appendix B: HPL Group Homework

A colleague of yours, Dr. Green, who is the director of a privately managed biomedical research laboratory in Washington DC, has contacted you for advice on a recent ethical dilemma that has arisen in her lab.

Her lab is regarded as the international leader in neurological research to help cure sufferers of Parkinson's, Alzheimer's, and other neurological diseases and traumas. The lab is primarily funded through NIH grants.

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You have been asked to consider this question from one of several perspectives that might be relevant.

- Describe a plan of action for making a decision in this case from your assigned perspective.
- You can use the resources from Research and Revise, the videos shown in class, and any other resources you find relevant to research the question.
- Using this plan of action, describe and justify your final recommendation in two pages.

Perspectives:

a) As the attorney retained by the lab to advise them on regulatory issues, how do you recommend Dr. Green proceed with this situation?
b) As the Program Director for the National Institute for Neurological Disorders at NIH, how do you recommend Dr. Green proceed with this situation?
c) As a lobbyist for the National Right to Life Organization, how do you recommend Dr. Green proceed with this situation?
d) As a personal friend whose child suffers from multiple sclerosis, how do you recommend Dr. Green proceed with this situation?
e) As the chief financial officer for the research lab, how do you recommend Dr. Green proceed with this situation?

Appendix C: Challenge 2

Four years have passed and a groundbreaking study by a competing lab in Britain has demonstrated a technique that allows doctors to apparently cure Parkinson's disease in 95% of patients – an unprecedented survival rate for any neurological disease of its magnitude. Each time the therapy is used, stem cells must be extracted from a new human embryo.

The Food and Drug Administration recently approved the therapy based on the strong evidence of its efficacy in British clinical trials, but the 2001 executive order on stem cells is still in effect and therefore federal Medicare dollars will not be used to reimburse this treatment. The expensive therapy is therefore unavailable to many elderly or low-income patients.

A bill to overturn the 2001 presidential executive order and encourage widespread availability of the treatment has passed through Congress and awaits a vote in the Senate. If it gets to the White House, the president is expected to sign the bill. His father was recently diagnosed with Parkinson's.

Your research in the last several years has been an almost identical approach as the British group, but your results in primates have demonstrated that subjects treated with this therapy might painfully and fatally reject new stem cells about four years after the treatment. You feel that the British group's research may not be mature enough to see any adverse effects in the clinical trials, and that humans treated with this therapy will have a chance of rejection similar to your primates.

You have been subpoenaed to testify in front of the senate healthcare committee before the upcoming vote. You must decide to what extent the public needs to know about your primate results.

In a new group (composed of different homework perspective groups), collectively decide on the best way to approach this dilemma.

For starters, consider these questions:

- What are the possible alternative actions you could take?
- What are the consequences of each of these alternatives?
- What responsibilities do you have as a scientist and citizen?
- If these responsibilities conflict, how do you weight their importance?
- Whose advice will you seek?

Appendix D: Lecture Group Homework

Introduction to Biomedical Engineering
Homework

Use the materials from last week's class as well as extra resources you find on the Internet to answer the following questions.

1) Describe George W. Bush's August 9th (2001) executive order. What is the central compromise in the order?

2) What viewpoints were likely considered to arrive at this compromise presented by the US government?

3) Describe five potential benefits from stem cell research.

4) Describe the differences in adult, umbilical, and embryonic stem cells with regard to their research or therapeutic potential.

5) What underlying ethical principles form the foundation of the argument from the pro- and anti- embryonic stem cell research viewpoints?

Appendix E: Pre- and Post-test Questions

Factual Questions:

1) What are embryonic stem cells?
2) What are the regulations on using stem cells for research in the United States?
3) What are some of the potential benefits of stem cell research?

Adaptive Expertise Question:

Read the article below. Write a one-paragraph letter to congress on why the panel's recommendation should or should not be followed.

Stem cell lines have limited value – Panel advocates starting new lines

Julie Bell, *Baltimore Sun*, Nov. 11, 2003

The human embryonic stem cell lines eligible for federally funded research are unsuitable for use in humans because they were grown in contact with mouse cells and could conceivably infect humans with mouse viruses, a panel convened by scientists at Johns Hopkins University said Monday.

The group, formed last year to address "the next generation" of ethical questions associated with stem cell research, also argued that treatments derived from the limited number of approved stem cell lines would benefit only a limited number of Americans and could discriminate against racial minorities.

The scientists proposed a controversial long-term solution: starting a new stem cell "bank" by identifying and soliciting a diverse range of donors, creating embryos and then destroying them to get cells for therapeutic use.

Your letter: