IT'S FUN, BUT IS IT SCIENCE? GOALS AND STRATEGIES IN A PROBLEM-BASED LEARNING COURSE

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All students at Hampshire College must complete a science requirement in which they demonstrate their understanding of how science is done, examine the work of science in larger contexts, and communicate their ideas effectively. *Human Biology: Selected Topics in Medicine* is one of 18-20 freshman seminars designed to move students toward completing this requirement. Students work in cooperative groups of 4-6 people to solve actual medical cases about which they receive information progressively. Students assign themselves homework tasks to bring information back for group deliberation. The goal is for case teams to work cooperatively to develop a differential diagnosis and recommend treatment. Students write detailed individual final case reports. Changes observed in student work over six years of developing this course include: increased motivation to pursue work in depth, more effective participation on case teams, increase in critical examination of evidence, and more fully developed arguments in final written reports.

As part of a larger study of eighteen introductory science courses in two institutions, several types of pre- and post-course assessments were used to evaluate how teaching approaches might have influenced students' attitudes about science, their ability to learn science, and their understanding of how scientific knowledge is developed [1]. Preliminary results from interviews and Likert-scale measures suggest improvements in the development of some students' views of epistemology and in the importance of cooperative group work in facilitating that development.

Introduction

When Hampshire College was founded in 1965, its mission was to experiment with structural reforms of teaching, curriculum, and institutional design [2]. Faculty were expected to create new course structures that encouraged students to ask questions about what they wanted to learn about and what they were taught [3]. The science curriculum that evolved incorporates active learning strategies in courses and projects throughout the curriculum, starting in the first year [4].

All Hampshire students are introduced to science in small freshman seminars in which they engage in laboratory, field, or literature investigations. To complete the science requirement, students must demonstrate they have satisfied five criteria [5] that can be summarized as follows:

- Engage in scientific inquiry and develop a sense of ownership for their work
- Recognize and ask good scientific questions, assess the quality of experimental design, and examine relationships between data and conclusions
- Use quantitative information intelligently
- See the work of science in larger contexts
- Communicate ideas effectively orally and in writing

Students can't achieve these goals without learning and applying content and understanding the conceptual framework of their work. The "science" of the science requirement asks for more depth of understanding and a better ability to use information intelligently and analytically, than does a science requirement based on completing a class in which a certain amount of material about a subject in science has been covered. Students take science classes and they learn content, but that alone will not suffice. The challenge for faculty is to design courses that help students achieve these goals and to be able to recognize when students have succeeded.

College science faculty are not, typically, conversant with current literature on learning theory and teaching strategies. We design courses based on knowledge of our disciplines and on how they have been taught before. We may incorporate teaching strategies that worked for us as students or new ones that we heard about informally, but rarely do we search the education literature for ideas. This paper outlines the evolution of *Human Biology* over the past six years as we, along with other Hampshire faculty, attended Science, Technology, Engineering and Mathematics Teacher Education Collaborative (STEMTEC) institutes (supported by the National Science Foundation [NSF]), Project Kaleidoscope conferences, and a series of workshops at Hampshire College funded by the NSF Institutional Reform program (IR) and the Howard Hughes Medical Institute (HHMI). Through work with K-12 teachers, college science faculty, and educators from other institutions, we were introduced to strategies designed to promote active learning in science classes.

Human Biology: Selected Topics in Medicine is a focused, inquiry-based science course designed to help freshmen develop skills they need to complete the science requirement at

Hampshire College. A website for the class [6] includes details of the syllabus, instructions for groups doing casework, and expectations for students. This site also links to sources of medical cases designed for teaching human biology.

Described here are the structure of the course, changes made in the course over six years, examples of the kinds of work students did, and approaches used to assess student work. It was apparent as the course evolved that it was necessary to clarify the extent to which innovations in the course improved students' skills, knowledge, and attitudes about science. Preliminary results of assessments of introductory science courses at Hampshire College have been published or presented at professional conferences (such as the International Meeting on Science Education in Cuba, 1999), and we report here some of the findings that apply to this course [1,7,8,9].

The First Two Years

Six years ago, *Human Biology* was completely redesigned. A presentation made by M.A. Waterman (at Westview State College in 1995) at a Partners Advancing the Learning of Mathematics and Science (PALMS) conference—the Massachusetts NSF State Systemic Initiative—moved us to adapt the Harvard Medical School case-based approach for our undergraduate class. The first two years we taught the course, 30-35 first-semester college students worked in problem solving groups of 10-12 on three medical cases. The class met twice a week for ninety minutes each, and it included students who intended to major in science as well as students taking the course primarily to satisfy the science requirement.

Human Biology was not intended to be a survey of all human systems. Content in human biology consisted of material pertinent to the cases studied. We followed closely the approaches described by Waterman and Maitlin for problem-based teaching of medical cases [10,11], and we used medical problems based on real cases written for case-based teaching by faculty and staff at Harvard Medical School [12]. Each group included a faculty member or an undergraduate teaching assistant who facilitated discussion but did not lecture. After each case was solved, faculty gave lectures to provide background and depth students might have missed. Each student then wrote a detailed case report presenting the reasoning and evidence used to develop the differential diagnosis.

In the Harvard curriculum, cases are said to take 2-4 days to solve. In our class for freshman, cases were scheduled for six to ten classes (over 3-5 weeks), depending on the complexity of the case. Information about each case was presented to students progressively as needed. Teams organized their discussions around three questions:

- What do we know?
- What do we think we know? (list hypotheses)
- What more do we need to know?

The questions asked in response to "What more do we need to know?" fell into two categories:

- those that students could look up in resources we provided or recommended
- those that required more information about the patient (history or test results)

Separating questions into these lists helped students understand the difference between observations and interpretations. As recommended in the literature cited above, we did not answer questions or provide more information until students had thoroughly pursued material they could look up or work out themselves. When we did present new information, the cycle was repeated (Table 1). When all the case teams had narrowed down the final diagnosis with recommendations for treatment and follow-up, we gave out the final page, which usually confirmed their conclusions.

Case Approach
Teams receive and read "Page One"
What do we know?
What do we think we know?
What more do we need to know?
Teams assign learning tasks
Individual homework assignments
Report findings to team
Repeat cycle until case is solved

Table 1. Segments of each medical case were presented to teams who then followed this cycle of activities. The amount of time spent on each segment depended largely on the complexity of the case.

Throughout the case, students completed a variety of writing assignments (Table 2): some related directly to the case and others were designed to teach students to find and read analytically, primary research articles. Detailed explanations of these assignments are included in the class website [6].

Writing Assignments
Case logs
Interim case reports
Final report for each case
Statistics problems
Experimental design analyses
Article summaries and revisions
Final paper

Table 2. Homework assignments provided practice in finding and reading primary research articles and in developing background for the case groups.

The case team approach turned out to be a stimulating, challenging, and motivating experience for students. They spent lots of time in the library with medical texts; they gave informal presentations to their groups; they held lively discussions in and out of class; and, they wrote case reports and final papers that were more analytical than one typically sees from first-semester college students.

As faculty, we still had concerns that some of our goals for students were not being served. For instance, in previous versions of *Human Biology* we introduced students early to analytical reading of primary research articles [13]. In the case-team approach, students had no opportunities to examine experimental design and start to grapple with simple techniques of data analysis. We also noticed that although all students in the case teams appeared interested, three or four in each group were so quiet that we weren't certain how much they were learning until we read their final case reports. Conversely, some students tended to take over discussions and influence other students by their confidence, even if the information they presented wasn't always correct. We also found that the lectures we gave at the end of each case did not always answer questions students had, sometimes rehashed material they already knew, and often included everything we wanted them to know but feared they had missed. We packed so much information into one or two lectures (that we believed were well crafted), we suspected that much of it wasn't retained for long.

After the Institutes

As a result of what we learned in these programs and related literature, numerous small but important changes were made in the structure of *Human Biology*:

- group size was decreased from 10-12 to 4-6 students per group
- faculty did not sit in with any one group; instead, we listened in and moved from group to group
- strategies of formal cooperative groups were instituted [14,15]
- students were assigned team roles (facilitator, recorder, skeptic, fact checker, task manager) and given instructions about how to fill these roles [6]
- the semester started with short small group activities designed to build team skills and introduce the case solving process [16-20]
- mini lectures were integrated throughout the case in response to questions being asked, instead of being held at the end
- classes included times for low risk writing [21] to help students focus their attention on class activities or to articulate questions to ask us in class or privately
- students submitted short periodic reports on their case work before the final case reports were due
- feedback was solicited throughout the semester about what was working well for students and what wasn't
- peer evaluation of team participation followed the conclusion of each case (Course Packet/Peer Evaluation Form) [6]
- analysis by the teams of a primary article was substituted for one case
- jigsaw activities were used in which teams of students each learned one part of a primary article well, and those teams split up so that members of the original teams taught what they knew to those in their new teams [22]
- assignments focusing on statistical analysis of data presented in the primary articles were added

After we instituted these changes, more students took active roles in the groups, and all students knew they needed to contribute to group research and discussion. Almost immediately, it was possible for us to identify problems in group dynamics and misconceptions about the material and to respond to them. Students were very motivated and many did considerable library work and scheduled team meetings outside of class. When faculty acted as facilitators rather than leaders of groups, students developed their own strategies to direct their learning. They realized that they were responsible for making their groups work and that they needed to pull together information from a variety of sources to construct knowledge to resolve the problem.

Topics students chose for final papers were similar to those students wrote about in previous versions of the course. However after the changes we made, students' writing showed an increased understanding of the structure of primary scientific articles and how to properly cite resources, and most student papers included detailed discussions of two or three primary research articles. Sample final paper titles:

- Medical Assessment and Treatment of Pain
- Maternal Cocaine Use and Possible Effects on Perinatal Outcome
- Formation and Metastasis of Malignant Neoplasms
- Contemplating Creatine
- Gene Therapy: How successful is it really?
- Effects of the HIV Virus on Cellular Immunity
- Unemployment as a Risk for Cardiovascular Disease
- Causes, Impact, and Treatment of Polycystic Ovary Syndrome

Example of the Start of a Case

A typical case began by handing out a page that introduced the problem (referred to as "Page One"). This might be a summary of a patient's visit to a doctor's office and the symptoms the patient reported (medical history). Or, as in the example shown below, Page One might be an emergency situation that needed to be evaluated medically [23] with recommendations about what to do next.

Letitia Dorsi's Fall
Page One

> On the night of October 25, 1992, Letitia Dorsi, a 53-year-old woman, was returning from dinner with her husband and asked him to double park while she ran into the drugstore to get toothpaste. On leaving the car and taking three fast steps, she tripped on a raised corner of concrete and fell flat.
>
> She was holding a cape around her, so when she landed on the cement sidewalk, her knees, shoulder, and head all hit at once. She was winded and couldn't speak for a few minutes. Her glasses were broken, blood was running down her face, and her knees were scraped and bleeding. But when her husband helped her up, she insisted she was o.k and said she had to get home to prepare a lecture for class tomorrow. Despite her assurances, he drove her to the home of a doctor friend who lived nearby to see if he thought she should have stitches.
>
> The doctor said, "The abrasions on your patella aren't deep, but they should be cleaned and dressed. The contusions on your head don't look too bad, and for cosmetic reasons you may want to get the flap and puncture-type lacerations stitched. But why are you holding your left arm like that? Given the brachial neuroplexopathy of your right arm, you'd better have your left shoulder looked at in the emergency room."

Students read Page One to themselves and then the team facilitator read it aloud. The student acting as recorder listed on newsprint, so that all team members could see, what the team decided they knew, what they thought they knew, and what they needed to know. Typically, case teams generated 10-15 items for each list. For the case shown above, students in one class listed (among other things): they knew Ms. Dorsi was 53 years old, married, fell on a sidewalk, and had some bleeding; they suspected she broke a bone in her arm, had a fainting spell, or had a concussion; and they asked, "How was she holding her arm? Did she really trip or did she fall for another reason? What is a brachial neuroplexopathy? Does she have medical insurance?" Technical terms were introduced early in the case so students could gradually build confidence using medical texts and dictionaries. Other pieces of information encouraged students to look beyond the obvious and find out more about the patient's history. Before class ended, team members assigned themselves questions from these lists to investigate.

At the next class, students shared the results of their homework assignments and constructed new sets of lists. The skeptic or fact checker was responsible for ensuring that information reported by team members wasn't accepted unconditionally: "How do you know that? Couldn't there be other explanations? Why would that happen?" This role was filled well by students who were confident about their background in science, but students who didn't think they knew very much biology often did the best job. Having the job of "fact checker" made it possible to ask questions the students honestly needed to ask. This process was repeated until the questions students asked could be answered only by learning more about the patient's history or test results. Then students were given "Page Two" ("In the Emergency Room...") and continued the process. Students can be seen working on a case about a hyperthyroid patient in a video [24] that focuses on a number of ways to use student-active teaching strategies in a variety of disciplines and classroom situations.

Formative Assessment

Students filled out feedback forms throughout the semester about the case process, content, and writing and library assignments. This feedback was invaluable to us in understanding what was working well and what mid course changes we could make. Sometimes when students expressed confusion or frustration, changes weren't necessary. Such comments provided openings for reminding students of our expectations of them and how the course structure was designed to support them. As we gained confidence that the goals were achievable and the approaches worked, we were better at conveying this to students and they were more confident about their progress.

Early in the semester, many students expressed concern that they wouldn't get the "correct" diagnosis. This provided a good opening to talk about the nature of evidence in actual medical situations in which the medical practitioner doesn't have an answer sheet at the end of the chapter. As they worked through cases, students learned about the importance of considering a full range of possible solutions and figuring out ways to eliminate those that didn't fit the symptoms or test results. We told students that they should avoid jumping at easy answers because they might miss a more important or subtle diagnosis. In addition, emergency situations, such as a patient with intense chest pain, required them to respond to possibly life threatening diagnoses such as myocardial infarction, before calling for tests to eliminate others (e.g., esophogeal reflux or muscle strain).

Often students asked what would happen if they came up with a diagnosis different from that eventually presented in the case. Our response was that if they could defend that decision effectively, they would have done a better job than if they happened on the "correct" diagnosis by luck without having reasons to back it up. Even if they chased down unlikely diagnoses that they eventually eliminated, they would have learned more biology than if they hadn't done that, and our evaluation of their work would reflect that effort and imagination.

Assessment of Student Work and Evaluation of Course Goals

At Hampshire College, students receive one page narrative evaluations of course work instead of letter grades. At the end of the semester in *Human Biology*, each student submitted a portfolio that included all written work and a reflective self-evaluation. Students also submitted peer evaluations of their contributions to team work [6]. By reviewing the semester's body of work for a student, we were able to assess students' progress in satisfying the five criteria listed for completing the science requirement.

The NSF and HHMI programs supported evaluations of course innovations. This made it possible to determine the extent to which the course helped students develop skills needed to satisfy the Hampshire College science requirement. Outside evaluators developed pre- and post-course questionnaires, performed in-class observations, and conducted structured interviews with randomly selected students at the beginning and end of the course. Information was collected about students' attitudes and beliefs about science, critical thinking abilities, self-reported gains in skills, backgrounds in science, and interests in pursuing science further.

Much of this assessment was coordinated, carried out, and reported by Laura Wenk [7] who worked with an assessment group from Dartmouth College (Evaluation Works, Korey Associates based in Norwich, Vermont) and one from the School of Cognitive Science at Hampshire College [25]. Our course was one of eighteen introductory science courses Wenk and her colleagues studied at two four-year colleges.

We were interested in examining changes in students' epistomology in science. That is, what was students' understanding of the nature of scientific knowledge? More specifically, what methods did students use to justify decisions and what was their understanding about how scientific knowledge is constructed? Data about these developmental issues were collected from students in introductory science classes through three means: pre- and post-semester interviews with students chosen randomly (faculty did not know which students were being interviewed);

pre- and post-semester Likert-scale surveys on students' attitudes and beliefs about science; and, post-semester Likert-scale student self assessments.

Preliminary results of the Likert-scale surveys showed that for most items on the surveys students showed positive trends but no significant improvements in their attitudes about science [8]. Nonetheless, those items that did show significant improvements had to do with greater appreciation of scientific thinking and greater understanding of the nature of evidence in science. Wenk reports that significantly more students agreed at the end of the course with statements like the following: "Even if I forget the facts, I'll still be able to use the thinking skills I've learned in science"; "I can back up my ideas in science." [8] Students disagreed more strongly with the statement, "Scientists publish their work in professional journals that are too technical for me to understand." In self-assessments, students noted that they felt better able to use scientific evidence to support their ideas, they could more critically evaluate a primary research article, and they could make better judgments about science issues reported in the newspaper.

In one of the workshops for science faculty, Wenk outlined current thinking about stages in adult understanding of how knowledge is constructed (Table 3). Literature reviewed by Wenk suggested that college seniors are typically at stage four or five and move to stage six after they've spent time working or in graduate school [8]. Faculty found that this developmental perspective offered a strong analytical tool for understanding progress in students' thinking. For example, before we recognized the existence of intermediate stages, we expected that first-year students who took one of the inquiry-based courses would jump from believing that knowledge comes from authorities to using rules of inquiry to understand evidence in context. We were disappointed if a student who wrote an excellent critique of experimental design and analysis of data suddenly approached a conflict in the literature by saying, "Well, everyone has his or her own beliefs, and that's o.k."

After Wenk's workshop, we were able to recognize significant progress in the development of students' ways of thinking that previously we had regarded as failures to reach our goals. Science faculty not familiar with the underlying research of stage theory wondered if these stage descriptions were somewhat arbitrary, but many of the ideas summarized in Table 3 rang true to most faculty who regularly read student papers in science.

Summary of Adult Developmental Stage Theory	
Stage	**Epistemology and Method of Justifying Decisions**
1	Knowledge is certain; authorities have the right answers.
2	Knowledge is certain, but disagreement sometimes exists. Decide based on what authority tells you.
3	Knowledge is certain in some areas, uncertain in others. Authorities may disagree because of bias. Decide based on what feels right.
4	Knowledge is uncertain. Everyone has his or her own beliefs; some are more logical than others. Decide based on evidence that supports beliefs.
5	Knowledge is uncertain, but some ideas are supported better than others. Look at evidence in making decisions. May need help in evaluating evidence.
6	Knowledge is known within a particular context and is limited by the perspective of the knower. Decide based on evidence, using rules of inquiry for that context. Disagreements may be due to contextual variables that the student can name and understand.

Table 3. This chart was adapted from Wenk [8] who synthesized ideas from developmental theorists such as Perry, Belenky, Magolda, King, and Kitchner

Excerpts from one interview reported by Wenk illustrate how interviews can provide evidence about students' understanding of the scientific process [1]. One student's response to the statement, "Every day, in more and more areas of science, the right answer is known. I look to experts to tell me what is right. In areas where no right answer is known, I think anyone's opinion is as good as another's" is excerpted in the quotes below from their pre- and post-course interviews:

Pre-course:

I think I agree with it basically....when there is a right answer that you know is going to be right and that you have the possibility of getting the answer wrong, then you just look to someone else to give you the right answer to teach you how to get the right answer. In areas where no right answer is known, I think anyone's opinion is as good as another's...

Post-course:

I think they kind of have this thing backwards a bit. I don't think that every day in more and more areas of science the right answer is known.... My mind has really started to change since I've been in school just about the way things work...It just seems like there are a lot more factors to it than just being like 'this is a study that came up with the right answer and this one says that it came up with the right answer too and so one of them is right and one of them is wrong'....It's more like maybe this study did it differently and maybe they went about it differently and maybe they were trying to find out something different....

One of the most interesting findings of Wenk's work is that with no teacher in the group, students were required to rely on their own research and problem solving skills more. Interviews with some students suggested that working in small groups without an instructor in the group helped students develop more sophisticated strategies for coming to decisions than would have been possible if students worked alone and turned only to faculty for answers. For example, if the information one student found supported one hypothesis and the information another student on the same team found rejected that hypothesis, each student needed to justify the diagnosis they presented with evidence. They couldn't just say, "One person's opinion is as good as another's." They needed to dig deeper, compare the information in more detail, re-examine the original hypothesis, and develop others. Many students who wouldn't have had the confidence to carry on this kind of critical discourse with a faculty member did so with other students.

What We Learned

So is this science? We think so. On the basis of Wenk's survey data and her interviews with students, we are more confident that students in the course are learning science [8]. They read and evaluate scientific studies to learn how scientists ask questions, design experiments, and evaluate data. Their summaries of these papers show healthy skepticism as well as an appreciation of the limitations to designing perfect experiments. The final papers they write for class demonstrate that they learned and can use content necessary to read and write about scientific questions with some confidence. What's more, their work shows that as they gain confidence in what they can do and what they know, they start to understand how much they don't know, but that doesn't discourage them.

Is it fun? Excerpts from self-evaluations of four students are typical and sound as though the students are enjoying the course, even as they are working harder:

"Being faced with the challenge of finding large amounts of information that was relatively new to me and actually going out and finding it created in me a great sense of accomplishment."

"I enjoyed the way the class was structured."

"The cases definitely tested my ability to revise and re-think and revise again."

"I must say that I am very proud of my progress."

Is this course perfect? Not even close. But we are much closer to achieving our goals for students than ever. Changes made in course structure as a result of what we learned in curriculum workshops helped us solve our original problems. Students show:

- increased motivation to pursue work in depth
- more active participation in case teams
- deeper critical examination of material gathered from medical texts and journals
- greater development of arguments in case reports

We have learned a lot from colleagues across the country. Resources exist for faculty who want to learn how to use case-based and problem-based learning in science courses [15,17,26]. Many faculty write their own cases and publish them in journals and on-line for others to use [27]. Each year we look forward to working on new cases. We're still having fun, too. ■

Acknowledgments

This material is based upon work supported by the Howard Hughes Medical Institute (Grant # 80013601) and two grants from the National Science Foundation (Grant #DUE 9653966 and Grant #9552886). Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation or the Howard Hughes Medical Institute.

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