Case Pedagogy in Undergraduate STEM: Research We Have; Research We Need

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Mary Anna Lundeberg

What is Case Pedagogy?

A promising practice in the STEM undergraduate classroom in the last 15 years is the use of case studies that use realistic or true narratives—that is, stories, to educate (Herreid, 2007). Cases are more than just stories, however; they involve an authentic portrayal of a person(s) in a complex situation(s) constructed for particular pedagogical purposes. Two features are essential: interactions involving explanations, and challenges to student thinking. Interactions involving explanations could occur among student teams, the instructor and a class, among distant colleagues, or students constructing interpretations in a multimedia environment. Cases may challenge students' thinking in many ways, e.g., applying concepts to a real life situation; connecting concepts, sometimes interdisciplinary ideas; examining a situation from multiple perspectives; reflecting on how one approaches or solves a problem; making decisions; designing projects; considering ethical dimensions of situations. Brief vignettes, quick examples, or unedited documents are not cases.

Originally, cases were used in law schools to develop jurisprudence, that is, legal reasoning. In addition to developing reasoning, cases used in professional courses develop students' theoretical and practical understandings of concepts, metacognition (thinking about thinking), and social, ethical and epistemological growth (see Lundeberg, 1999, for an extended discussion of each of these ideas in teacher preparation). This promising practice has been used in many STEM disciplines (see Barnett, 1991 for mathematics; Herried 1994 for science; Standridge, 2006 for technology; Prince & Felder, 2006 for engineering), and in a variety of instructional settings, ranging from the Socratic discussion method used in business, law schools, and seminars, in which the instructor plays a key role in leading the discussion, to PBL and Team Learning, with the emphasis on student-led small-group, cooperative teams, used in lecture, lab and seminar settings (Herreid, 1994, 2007). Generally, faculty intersperse case methods with lecture methods: 88% of the faculty we surveyed reported using between 1-5 cases per semester and most of these cases (66%) took one class period or less to complete (Yadav, Lundeberg, DeSchryver, Dirkin, Schiller, Maier, & Herreid, 2007).

All cases are not equal. Prior to using a case think about this question: 'What is this a case of?'(Shulman, 1999). When examining research on using cases in STEM education, ask: Cases of what? Taught how? To whom? For what purpose? Within what kind of program? For how long? (Shulman, 1999). Just as a case of pop differs from a case of wine, so one case study in one course period will likely have less effect than an extended case used for several weeks. For example, the cases available on the National Center for Case Study Teaching in Science website (http://library.buffalo.edu/libraries/projects/cases/case.html) generally last one 50 minute class session, and do not require outside student work, whereas the multimedia case project, Case It! (http://caseit.uwrf.edu//caseit.html) may last as long as a month, with time for independent student research, communication and writing during that time period.

Shulman's (2002) framework is useful for categorizing some outcomes from teaching with cases:

> In a nutshell, the taxonomy makes the following assertion: Learning begins with student engagement, which in turn leads to knowledge and understanding. Once someone understands, he or she becomes capable of performance or action. Critical reflection on one's practice and understanding leads to higher-order thinking in the form of a capacity to exercise judgment in the face of uncertainty and to create designs in the presence of constraints and unpredictability. Ultimately, the exercise of judgment makes possible the development of commitment. In commitment, we become capable of professing our understandings and our values, … our skepticism and our doubts, internalizing those attributes and making them integral to our identities. These commitments, in turn, make new engagements possible—and even necessary. (p.37)

Because cases motivate and engage students, instructors use cases with introductory as well as upper-division students. Motivational purposes range from engaging non-majors in appreciating the real-world relevance of global issues to inspiring majors to consider ethical ramifications of professional decisions. Cases deepen knowledge and understanding when students explain ideas verbally or in writing, and integrate concepts across several areas (Lundeberg, 1999; Herreid, 1994). Cases seem particularly useful for enabling students to gain knowledge and understanding of how interdisciplinary issues are influenced by global, ethical and societal contexts, or how systems interrelate. Some cases involve performance and action, such as investigations, including lab simulations that require students to analyze data, interpret results and connect ideas, experiences, patterns and explanations. Such explanations generally involve decisions, and if students role-play various perspectives, they may reflect on and critique these decisions (or designs) using multiple viewpoints. Cases may also engage students with ethical and societal problems related to their discipline (e.g.,). For upper-level students, cases provide contexts to do extended research, complete reports or professional projects, which may strengthen their commitment and identity within a discipline.

There is disagreement in the field regarding how much knowledge students need before they engage in case-based learning; in general those who are using a problem-based learning approach (Allen, 1996; Barrows, 1998), generally use a case as an anchor to situate students' conceptual knowledge and to encourage students to research related ideas, prior to giving lectures on this information. In contrast, some case-based faculty prefer to use cases as opportunities for students to synthesize knowledge across several lectures or units (Bergland, Lundeberg, Klyczek, Hoffman, Emmons, Martin, Marsh, Sweet, Werner, Jarvis-Uetz, 2006). Other case-based instructors use a case as a basis for a lecture, taking time to allow for some student discussion or student responses to questions. One study found that using cases as an anchor prior to lectures (story before theory) promoted more conceptual understanding than using cases after lectures (theory before story) (Lundeberg & Scheurman, 1997). Work on expert reasoning, such as law, shows that knowledge interacts with reasoning and reasoning about cases develops further knowledge (Lundeberg, 1987).

Cases do not teach themselves. Another disagreement among faculty centers on how much task structure and facilitator guidance students need to analyze cases, even within introductory courses. For example, clicker cases are very structured, and faculty ask students explicit questions in a relatively brief time period, guide responses, and generally probe students' responses for explanations. In contrast, when student teams use CaseIt!, they take responsibility for a range of decisions, from which procedures to use in open-ended simulations to how to interpret and present their findings on a web poster and what to discuss with distant colleagues. To prepare for Socratic large group discussions students generally write case notes. However, some faculty provide case-specific questions for students to respond to, whereas others use a more general heuristic format, similar to law school, in which students have to write about the issue (or what is going on in the case), what they know (e.g., the facts) what they don't know (their questions), concepts and theories that pertain, the action (or their decision) and potential consequences, depending on whose perspective on considers.

Rationale for Four Examples

By providing four concrete examples, I hope to illustrate the diversity of case study teaching in four contexts and to connect research to these examples: 1) A case from the National Center for Case Study Teaching in Science used in a seminar about Global Change Biology 2) Clicker cases used in large Introductory Biology lecture classes, 3) Extended problem-based multimedia cases used in Biology labs: CaseIt!, and 4) Project-based scenarios used in Engineering classes. Each situation defines case-based teaching somewhat differently, even though they share similar goals of engaging students in connecting important disciplinary concepts to authentic, complex contexts.

Example 1): Case Used in a Seminar for Non-majors

The Deforestation of the Amazon: A Case Study in Understanding Ecosystems and Their Value(http://ublib.buffalo.edu/libraries/projects/cases/amazon.html)

Phil Camill developed this case for a sophomore-level course in global change biology that enrolled fewer than 100 students (48 enrolled in 2000). The course fulfills a requirement for non-biology majors, and is an elective for science majors. To enable students to examine the multidisciplinary complex nature of environmental problems, they critically investigate tropical deforestation in the Amazon and perform a benefit-cost analysis of clearing a plot of forest land using one of three perspectives: a peasant farmer, a logger, and an environmentalist. After students prepare positions in teams, the instructor facilitates a discussion to meet 8 higher order-learning objectives. Four objectives center on understanding history leading to deforestation, issues facing stakeholders, concern for biodiversity and concepts in valuing ecosystems. The other four objectives include "5. Perform a benefit-cost analysis…6. Critically evaluate economic vs. ethical valuation of ecosystems, 7. Appreciate the political, social, economic and ecological complexity of tropical deforestation. 8. Appreciate how difficult decisions must be made in the face of limited or nonexistent data." During a 70- minute class period, students work in groups to compare case notes and construct their benefit-cost analysis, followed by a large group Socratic discussion facilitated by the instructor. Students then write a 2-3 page report summarizing questions discussed in class (see case notes for more specific information). (http://ublib.buffalo.edu/libraries/projects/cases/amazon_notes.html)

Example 2): Clicker Case used in Large Lecture courses

Cross-dressing or Crossing-over: Sex Testing of Women Athletes, ***http://www.sciencecases.org/crossing_over/prelude.asp***

The use of case studies in large classes (100+) is hampered because discussion rarely occurs, or is dominated by a small minority of students, as low as 10-20% (Horowitz, 1988). "Clickers" (Personal Response Systems) are a feedback system that allows case study teaching to be introduced into large lecture classes, since most case studies depend on interaction to discuss concepts within cases (see http://www.sciencecases.org/clicker/herreid_clicker.asp for a more extended description of clicker cases).

In this clicker case, the story of Santhi Soundararajan, a female athlete from India who was stripped of her Olympic medal after failing to pass a sex test, provides a context for students to understand meiosis, sex determination and chromosomal "crossing over". The authors, Maureen Knabb & Joan Sharp (2008), who developed this case to use in their large introductory biology classes, engage students in Santhi's story through an Internet video, and then present the case via 34 PowerPoint slides so students the historical context for gender testing in athletes, discuss criteria for determining whether someone is male or female, imagine they are members of a Olympic committee to determine whether Santhi is female and eventually make a decision about what they would do, given her karyotype. (http://www.sciencecases.org/crossing_over/notes.asp) This PowerPoint Clicker case contains clicker questions that review the process of meiosis and includes links to animations that illustrate how chromosomes assort independently through meiosis.

While clicker cases may have slides of data for students to interpret as part of their decision making process, some multimedia cases contain simulations so students conduct investigations and then interpret the results they obtain. These kinds of cases are generally more involved, and require student research and writing, which takes more class time than clicker cases, or many of the other cases on the National Center for Case Study Teaching Website.

Example 3) Problem-Based Multimedia Cases Used In Biology Labs:

Case it! http://caseit.uwrf.edu/.

Case It! is designed to enhance learning about genetics and infectious disease around the world, and is freely available. The Case It! learning environment is multifaceted and allows students to interact using three separate tools: Case It Investigator, Case It Simulation, and Case It Launch Pad (Bergland, Klyczek Lundeberg, 2006). *Case It! Investigator* (Fig.1) enables participants to view video cases and gather background information about their case.

Figure 1. Video case of an African with HIV/AIDS

Case-It! Simulation software enables students to simulate the laboratory tests of several genetic and infectious diseases, including HIV. For example, students using simulation software can run ELISA as an HIV test screening procedure as well as a Western Blot to confirm ELISA results, and Polymerase Chain Reactions (PCR) to test the viral loads of their patients' case. The software depicts an actual lab and allows students to make mistakes.

Case It! Launch Pad enables students to access *a Web Page Editor* or *Internet Conferencing system.* After running analyses using Case It! simulation, students take photos of the resulting gels and blots, and then incorporate them into web pages via a web page editor. They construct web page posters reporting results of this HIV/AIDS testing, explaining the results to the case "patients" and giving treatment and ethical/social advice. Examples of web posters created by a student teams can be accessed through the website (http://caseit.uwrf.edu/). During web conferencing, students play the role of laboratory technicians, counselors or doctors when they respond to questions raised about their webposters, and switch roles to that of a family member or patient when asking questions about the webposters created by their peers. For an extended description of this, see (Bergland, Klyczek & Lundeberg, 2006, http://caseit.uwrf.edu/IJL.pdf).

Example 4) Project-Based Scenarios Used In Engineering

Typically, engineers are needed to create projects and to improve existing projects by using a variety of problem solving skills, project management skills, and teamwork skills that are learned through a combination of case-based, problem-based, project-based and team-based learning (Prince & Felder, 2006; Zemke & Zemke, 2007). Prince & Felder (2006) give examples and definitions of each of these within an engineering context.

In engineering, project-based cases help to encourage active participation by exposing students to real structures, problems, and aspects of the engineering field (Palmquist,

2007). Typically, students work in teams of 3-4 students per team towards solving ill-structured problems presented in class by the instructor. These problems have typically not been covered in class; hence providing students with opportunities to learn independently, work in teams to share their understanding, and increase their problem solving skills. Generally, students complete projects based on these cases, such as building circuits using a breadboard, and might write a short report describing their decisions. Engineering cases have also been used to teach ethics, such as acknowledging mistakes, confidentiality, conflicts of interest, honest, loyalty, product liability, safety and health, as well as others found on this website:
http://wadsworth.com/philosophy_d/templates/student_resources/0534605796_harris/cases/Cases.htm
For additional examples of cases, see the Center for Case Studies in Engineering (http://www.civeng.carleton.ca/ECL/), the *Journal of College Science Teaching* or the *Journal of STEM Education* (*http://www.jstem.org*), which regularly publishes case studies.

What Does Research On Case-Based Teaching Tell Us?

Research questions can be classified into three categories:

1. Description—What is happening?
2. Cause—Is there a systematic effect?
3. Process or mechanism—Why or how is it happening? (Shavelson, Towne, and the Committee on Scientific Principles for Education Research, 2002, p.99).

In general, faculty enthusiastically describe their experiences with case pedagogy, noting that it brings "real-world" relevance and fosters understanding of both scientific and societal of dimensions of important problems. However, we know more about faculty and student perceptions of the value of case-based teaching, than about student actual performance (Lundeberg & Yadav, 2006).

Descriptive Research: Perceptions of the Efficacy of Case-based Teaching

Most published studies on case-based teaching are limited to one classroom, and involve descriptive evidence, such as increases in test scores from one year to another, student opinions of cases or faculty descriptions of teaching with cases (e.g., Hoag, Lillie, & Hoppe, 2005). Individual classroom studies, in which instructors assess student performance through a comparison of scores from previous students indicate that case-based learning improves achievement (e.g., Dinan & Frydrychowski, 1995) or that faculty improve their teaching in subsequent years.

A national study of 101 faculty from 23 states and Canada who used cases from the National Center of Case Study Teaching in Science indicated faculty believed strongly in the efficacy of case-based instruction (Yadav, et al 2007). Faculty reported case-based teaching led to students' stronger critical thinking skills (89.1%), better ability to make connections across multiple content areas (82.6%), and deeper understanding of concepts (90.1%). Faculty reported that during case study teaching students were better able to view an issue from multiple perspectives (91.3%), and were more engaged in the class when using cases (93.8%).

In regard to student perceptions, undergraduate students generally report that content is easier to remember and apply when using case studies, and they experienced more interest and motivation to learn when using case studies in class (Hoag, et.al, 2005; Lundeberg, Levin & Harrington, 1999). Undergraduates reported that their confidence in understanding and performing basic engineering tasks improved, as did their interest (Sorby, Oppliger & Boersma, 2006). Students reported higher satisfaction with anatomy courses that used case studies, and more reflective learning (Kieser, Livingstone, & Meldrum, 2008). However, even though students reported learning more with the case method, this did not improve their attitude towards science, as measured by conventional questionnaires, such as the Student Attitude Inventory (Gallucci, 2007).

Some instruments for assessing affective outcomes, such as SALG (Student Assessment of Learning Gains) and the SAI (Science Attitude Inventory) can be useful in providing additional insight into why or how an intervention produced certain results (Galluci, 2007; Seymour, Daffinrud, Wiese, & Hunter, 2000). The SALG was developed to link instructional components of a course to students' perception of learning gains, and is particularly useful for instructors who want to customize questions (http://www.salgsite.org/). However, because attitude inventories such as the SAI generally measure stable traits, they may not be sensitive enough to assess changes in attitudes based on specific classroom practices. In-depth interviews are more sensitive to changes in values and attitudes; however, these need to be conducted by someone other than the instructor (e.g, Hoag, et.al, 2005).

Research On Systematic Effects and Processes involved in Case Pedagogy

Lundeberg and Yadav (2006a,b) argued for carefully designed research experiments to collect empirical data and assess the impact of case-based approaches on students' learning and conceptual understanding. Since the publication of that article, some rigorous classroom experiments have assessed the effects of case-based teaching.

Powerful Designs for Classroom Experiments

To study whether case-based teaching produces systematic effects, well-designed classroom experiments are needed (Lundeberg & Yadav, 2006a). The A-B-A-B (switching replications) design has powerful experimental control because it includes a direct replication of effect, i.e., the last two conditions (A_2-B_2) replicate the first two conditions (A_1-B_1) with the same subject, the same intervention and the same instructor (Tawney & Gast, 1984; Yadav, Subedi, Lundeberg & Bunting, in preparation). Thus, if one instructor wanted to conduct a classroom experiment, two units would be taught using the case based method (e.g., units 1 and 3) and two units would be taught using the comparison (e.g., lecture) method (e..g, units 2 and 4). When used with a Solomon Design, researchers can also control for effects related to pre-tests since half the population takes pre-tests and post-tests and half the population takes post-tests only.

Research on Conceptual Understanding in Biology using Clicker Cases

We used this A-B-A-B Solomon Design in a recent study with 12 biology faculty recruited from the National Center for Case Study Teaching in Science listserve to answer this question: Does using personal response systems ("Clickers") along with case study teaching improve understanding in large undergraduate courses? (Wolter, Kang, Lundeberg & Herried, under review). At the beginning of year 1, faculty decided on eight important topics in biology and developed cases on these mutually agreed upon topics common to introductory biology courses: cell theory, cellular division, Mendelian genetics, DNA, the scientific method, characteristics of life, cancer, and microevolution; they worked in teams to create 8 clicker cases, 8 PowerPoint lectures on the same topics pre/post test questions, and transfer questions. Each of these clicker cases were piloted in the team members' courses and revised. In year 2, faculty taught 6 or more of the 8 topics alternating the lecture or clicker case method. Half of the faculty taught topics A, C, E, or G via the case method and topics B, D, F, or H via the lecture method, thus alternating methods within the same course. The other faculty did the reverse, teaching topics A, C, E or G via lecture and topics B, D, F, or H via clicker cases. Thus, we compared within course performance on cases vs. lecture and between course performance, controlling for instructor effects, topic effects and for pre-test effects.

Students (N = 4,366) who used clicker cases performed significantly better on pre-test, post-test, and final exam assessments in five of the eight biology topics (cells, Mendelian genetics, cellular division, scientific method, and cancer), and in five of the eight transfer assessments (cells, cellular division, scientific method, microevolution and DNA). In 2 of the 3 topics (microevolution and DNA) students performed significantly better on the transfer question in the case condition, although there was no significant difference between the case and lecture treatments on pre-, post-, or final exam performance (microevolution), or students performed better in the lecture treatment (DNA). Students performed better on both assessments in the lecture condition on only one topic: Characteristics of life. Although students performed better in the lecture condition, faculty attributed this to the "lecture" being an interactive discussion with students, whereas the case was rigid and not interactive. Faculty thought the Characteristics of life case contained an extraordinary amount of text per slide, and reported this Clicker case did not contained a story that challenged students.

Conceptual Understanding in Electrical Engineering

Using an ABAB (switching replications) design to compare lectures with case-based teaching in an undergraduate electrical engineering course, we found that case-based teaching produced higher gain scores on applied conceptual problems than did lecture-based teaching (Yadav, et al, in preparation), although we found no differences in misconceptions among the two groups. These cases involved project-based scenarios using in the electrical engineering profession.

Research using Traditional Classroom Designs

The ABAB design, though powerful, is not always possible if there is only one case being evaluated, if the case is an extended case containing research projects that take up significant class time or if the researcher wants to compare effects of case-based teaching with lecture-only conditions. In those situations, the control group is typically another lecture class, often taught by a different instructor. Although this is not ideal, because of the confounding of different students and different instructors, studies such as these have demonstrated positive effects on student conceptual learning, ethical awareness and communication skills, and mixed results regarding critical thinking. For example, a meta-analysis showed significant gains in clinical application of knowledge and higher-order thinking for students using problem-based learning (a form of case-based teaching); however, no differences were found between student groups on standardized tests measuring accumulated knowledge (Dochy, Segers, Van den Bossche, & Gijbels, 2003). Students using case studies in introductory biology showed increases in conceptual changes regarding their understanding of genes, biodiversity and evolution, and reported in interviews that because cases made learning more interesting, relevant and motivating, they expected to remember concepts longer (Gallucci, 2007).

Critical Thinking in Science

A literate citizenry includes people who recognize and use science to help them reason in multiple contexts (AAAS, 1990; NRC, 1996). Critical thinking in science is generally thought of as scientific literacy. NRC (1996) defined scientific literacy as:

> Scientific literacy is the knowledge and understanding of scientific concepts and processes required for personal decision-making, participation in civic and cultural affairs, and economic productivity…Scientific literacy means that a person can ask, find, or determine answers to questions derived from curiosity about everyday experiences. It means that the person has the ability to describe, explain, and predict natural phenomena. Scientific literacy entails being able to read with understanding articles about science in the popular press and to engage in social conversation about the validity of the conclusions. Scientific literacy implies that a person can identify scientific issues underlying national and local decisions and express positions that are scientifically and technologically informed. A literate citizen should be able to evaluate the quality of scientific information on the basis of its source and methods used to generate it. Science literacy also implies the capacity to pose and evaluate arguments based on evidence and to apply conclusions from such arguments appropriately" (p.22).

In a recent report to the National Research Council, Duschl et al., (2007) explained that their framework of science literacy includes thinking of science both as a body of knowledge and as "an evidence-based, model-building enterprise that continually extends, refines, and revises knowledge" (p. ES-1).

Researchers who define critical thinking as some aspect of scientific literacy (e.g., identifying scientific issues, evaluating data, making decisions based on evidence) have found positive effects for case pedagogy. For example, students in a case study condition out performed students in a lecture condition in their ability to analyze data, and in their understanding of cellular respiration concepts applied to everyday life (Rybarczyk, Baines, McVey, Thompson & Wilkins, 2006). These undergraduates reported being engaged because they connected the concepts with a real-world scenario and used problem-solving skills. Moreover, students in the case study condition were "more likely to answer a question addressing misconceptions about cellular respiration correctly when compared with students who did not use the case study" (Rybarczyk, et al , 2006, p. 181).

Rybarczyk used an interrupted case similar to the ones on the National Center for Case Study teaching website.

Research on CaseIt! has indicated that students in the case condition were better able to interpret data and explain biotechnology concepts than students in the lecture condition, and case discussions were particularly useful for developing ethical awareness (Lundeberg, Mogen, Bergland, Klyczek, Johnson, MacDonald, 2002), and global perspectives on science issues, such as infectious diseases (Foster, Gwekwerere, Lundeberg, Phillips, Manokore, Bergland & Klyczek, 2006). Cases used with high school students have enhanced their understanding of environmental and moral conflicts and their scientific literacy skills such as question posing, argumentation and system thinking (Dori, Tal, & Tsaushu, 2007), as well as scientific reasoning (Lajoie, Lavigne, Guerrera, & Munsie, 2001).

Researchers using a general definition of critical thinking as applying concepts have found no differences between the case-study group and the lecture group. Using a historical post-test only design, Hoag, et.al (2005) compared the performance of a case-study group and a lecture-only group on five multiple choice questions measuring the ability to apply concepts, and found no difference on performance between the two section of students in a clinical immunology course. Terry (2007) measured biology students' abilities to think critically using the Watson Glaser Critical Thinking assessment and found no differences in performance between the case study group and the lecture group, although both sections significantly improved their performance.

Researchers in artificial intelligence have coined the term "case-based reasoning (CBR)" as an approach to learning and problem-solving using very structured cases, believing that humans generalize from cases by comparing features of new and previous cases and this comparison increases cognitive flexibility (Jonassen &Hernandez-Serrano, 2002; Kolodner, 1993; 2006; Spiro, Fletovich, Jacobson & Coulson, 1991).

Process Studies: Why or How are Cases Effective?

Theoretically, stories are a powerful mechanism for organizing and storing information (Jonassen & Hernandez-Serrano, 2002), and can enable students to make connections among systems and ideas, and to visualize ideas. A biology student explained in an interview how the CaseIt! simulation enabled her to understand the process of electrophoresis:

> …it just reaffirms what you hear in class but may not have grasped the concept because you may not have seen the whole visual makeup of it or whatever or understood things coming together, like DNA or deletions, point mutations. (Hershey, Lundeberg, Gerlach, Bergland, Klyczek, 2005).

Multimedia cases enable students to visualize processes, which contribute to their understanding if the student plays an active role (Diaz, Gomez-Albarran, Gomez-Martin & Gonzales-Calero, 2005), and dynamic geometry software can convey real-life situations, providing students with opportunities to verify experiments, conjecture and engage in constructing proofs (Guven, 2008).

Cases engage students, both by providing a real-life context that tends to spark student interest and by providing an environment that challenges their thinking. When asked about their reaction to the Case It! project, students in the US and in Zimbabwe reported that cases made the issues seem more real as illustrated by these comments:

> To me it was an eye opener…Since Zimbabwe is hard hit by HIV it is important to have this project CASE IT since it affects the students' lives at large. The videos shown are touching. These can help students feel it.
>
> The programme was also very interesting because it had cases of real people that got infected in different ways and situations…and the counseling they were given and how some observed the advice and some ignored this advice and got themselves into worse trouble. (Bergland, et al 2006, p.5)

Because they are challenging, and involve decision making in complex authentic situations, case studies capture students' attention, emotion and imagination, making learning more powerful than lectures (Prince & Felder, 2006).

Interactions promote learning, especially if students interpret data or create projects or reports in which they articulate their understandings. We videotaped student groups working through the Case It! Simulation and found students engaged in five aspects of scientific methodology: problem interpretation, discussing procedures (deciding which restriction enzymes and probes to use), performing experiments, interpreting results, and verifying results and procedures. An important advantage of the simulation was the opportunity to correct errors and redo their work if their results did not make sense (Bergland, Lundeberg, Klyczek, Sweet, Emmons, Martin, 2006). Creating a web poster and discussing this poster with peers challenged students to integrate knowledge, reflect on ideas and articulate their ideas (Bergland, et al 2006; Foster, et al 2006). Seventy-one percent (71%) of students reported being asked at least one question about their web poster on a genetic disease that they didn't know the answer to, which inspired them to do additional research and to revise their poster including this new information: "People are asking you questions that you don't know how to answer then you have to research it and answer them. So then you find out a lot more that if you just researched it and did a project." (Lundeberg, et al 2003, p.11)

Role-playing different people involved in making decisions about global issues is one component of small group work required of some cases (e.g., Camill's case on deforestation; CaseIt!), and may be invoked during case discussions of professional situations, such as the ethical cases on engineering. In a study tracing students' engagement in science learning through online discourse, the Case It! environment created emotional involvement, role-plays situated in cross-cultural networks made students aware of the social contexts involved in global issues, and research done in simulations promoted scientific competence (Kang & Lundeberg, under review).

Students using Case It! played the role of a genetics counselor when asked questions about their webposter and the played the role of someone in the case situation (e.g, patient or family member) when asking questions about their peer's posters. During interviews, a third of the students reported that interacting with peers about genetic cases provided them with a different perspective: "It [the role of the genetics counselor] introduces you to what people actually do and if you are in that situation, what happens." (Lundeberg, et al, 2003, p.11). This development of multiple perspectives was corroborated in interviews with students who interacted with international students about cases involving infectious diseases (Foster, et al, 2006). For example, this student in Zimbabwe reported:

> Case It gave me an opportunity to simulate HIV tests and play the role of a medical practitioner and counselor by giving advice to people affected by HIV. It was also interesting to network with international students via conferencing. Indeed, the world is a global village.

The US students reported: "it allowed me to see how it is to be HIV positive from both perspectives (person who is HIV positive and the AIDS counselor)", and "makes you want to learn more…able to see other opinions…and gave us a chance to talk to different places" (Foster, et al, 2006). We do not know, however, which kind of roles promote specific kinds of thinking and learning.

A few students using Case It! have commented that role-playing enhanced their communication skills, for example, "It was good because it taught us discussion skills because we had to tell the family what was going on." (Lundeberg, et al, 2002, p. 68). Discussing nutrition cases affected medical students' commitment to ask about patients' diet in their later clinical communication with patients (Dayal, Eerden, Gillespie, Katz, Rucker & Rosett, 2008). Communication skills are usually not assessed in research on case-based teaching, unless students assess themselves on teamwork, or by responding to peer's writing. We need to construct measures to assess changes in students' discourse that reflect their ability to become more scientifically literate, that is to engage in the kind of skeptical reflection and argumentation expected of citizens who understand the process of science.

Gaps In The Research And Areas Where Evidence Is Missing

Because how we teach interacts with what we teach and who we teach, research on practice is complicated. Who are cases good for? How might they facilitate understanding or engagement for different student populations? The National Academies (2007) report that in spite of the dependency of future national prosperity on increasing the numbers of scientist, engineers, and mathematicians, our universities are wasting the skills and talents of many individuals by discouraging and inhibiting women from fulfilling their potential in academic science and engineering. Studies that examine gender and cultural similarities and differences in learning are needed.

Because faculty use cases in a multitude of ways, and use different kinds of cases, we need more research investigating the effects of different kind of cases. How does student learning differ, depending on the nature of the case? How might multimedia cases contribute to or diminish students' engagement and learning? What kinds of cases are most relevant to students and does relevance matter, in terms of understanding? (Wolter, Lundeberg, & Bergland, under review). Are video cases more powerful than text cases (Dirkin et al. 2005)? How do students need to interact with the case, or with others, for learning to occur?

How the instructor interacts with students also matters and we have very few studies of classroom interaction at the undergraduate level (e.g., Henning, Nielsen, Hauschildt, 2006). What is the instructor's role in facilitating learning through case methods? Just at expert facilitators have been studied in the context of a PBL tutorial session, we need to examine how experienced professors, e.g., Clyde Herried, use the Socratic method to promote student thinking and to probe student responses (Hemlo-Silver & Barrows, 2006). How much authority and autonomy should be given to undergraduates? How much knowledge or background do students need?

A next step for demonstrating effectiveness of case study teaching in undergraduate STEM is to assess whether this method promotes scientific literacy in students. Does case pedagogy improve the ability of undergraduates to articulate and address urgent global issues affecting our physical and social environments (e.g., MacGregor, Middlecamp, Millar & Seymour, 2007)? Does it foster careful skeptical analysis and strengthen scientific argumentation? Does this pedagogy enable students to understand both scientific and social dimensions of complex problems? Does it enable students to visualize a systems approach to science? Bringing together STEM faculty working to improve postsecondary education and providing resources for national collaborative research groups to study promising practices across institutions may change some of the problems with undergraduate STEM education (e.g., Committee on Science, Engineering, and Public Policy, 2006; Kardash & Wallace, 2001, National Science Foundation, 1996). This endeavor will stimulate a stronger knowledge base regarding who learns what from cases and how, so we can improve the real-world relevance of STEM education.

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