Is There Enough Poison Gas to Kill the City?: The Teaching of Ethics in Mathematics Classes

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Introduction

Many mathematicians believe that mathematics is "pure," "beyond good and evil," and "value-free." Indeed, some would argue that the complete absence of an ethical component in (pure) mathematics is one of its defining characteristics. And although applied mathematicians may readily admit that their work sometimes has ethical implications, even many of them assume that it is inappropriate to discuss ethics in the mathematics classroom. As a mathematician I have been trained to be on the alert for "hidden lemmas," and, in that spirit, I would like to challenge this often unexamined assumption, and argue that it is not only appropriate but responsible to teach ethics in mathematics classes.

By Teaching ethics, I don't mean imposing my own (or someone else's) standards or values. I'm not trying to tell students what is right or wrong. Instead, I'd like to enable students to make explicit what their values are, encourage them to examine their bases and principles, and give them practice in making moral choices based on them.

I begin with some personal history, and share the stories of historical and contemporary mathematicians and scientists whose own struggles with ethical conundrums have inspired me. I conclude with some examples of methods to help students become more alert to ethical issues in mathematics.

Personal history

During the 1960s, I was a student at the Bronx High School of Science, and active in protests against the Vietnam War. I desperately wanted to find a role for science in society with which I could live. Also, like many in my generation, I was haunted by the threat of nuclear war, a threat made possible by the work of scientists during World War II. Younger readers may be haunted by threats to the environment, or biological warfare. Mine was neither the last generation, nor the first, to question the role of science in society.

The particular questions that obsessed me concerned the actions of World War II scientists on both sides: How could German doctors have participated in their awful experiments on human subjects? How could scientists and mathematicians have turned their backs on their colleagues who were being dismissed, deported, or exiled because they were Jews? What responsibility did the scientists on our side who were involved in the Manhattan Project that developed the atomic bomb, bear for the uses to which it was put, then and now?

At that time I found few satisfactory answers, and in fact, dropped out of college as a freshman. Thirteen years later I began my ten-year journey towards a doctorate in mathematics, with the intention of teaching the subject. I was still troubled by many of the same questions, but determined to raise them in my classroom, and thereby help the next generation confront these issues squarely. My determination was fueled by the examples set by role models.

Good people and perilous projects

Some of the scientists who worked for the Allies during World War II had afterthoughts about their participation in military projects. Towards the end of their careers, they reflected on the social responsibility of scientists and on their role in the arms race that followed the success of the Manhattan Project.

The first story I will tell is of the renowned mathematician and physicist, Freeman Dyson. As a child growing up in England, Dyson saw the horrific effects of the First World War, and vowed never to become a soldier. He studied mathematics and physics, "pure" subjects, seemingly far removed from war and soldiering. He was a pacifist, but he did accept job offers that utilized his scientific knowledge in support of the war effort. At the time, he saw his work as saving lives—lives of the Allies, that is. Thus, in the Second World War, Dyson worked for the War Department designing ever more efficient ways to bomb German cities. Reflecting on his position in later years, he expressed the conviction that morally, he saw his German counterpart as Eichmann. I saw the wry smile and pained look in his eyes in the televised interview where he made this statement. I asked myself, how does this happen?

I asked this question of Lawrence Senesh, an emeritus professor of economics, and one of my mentors at the University of Colorado. He explained that the analytical skills and concepts that we are taught as scientists, were inadequate and did not prepare us to grapple with the complex moral and ethical decisions that would confront us in our lives as professionals. He argued forcefully that "The moral imagination of future scientists must be stimulated," and that we needed practice making moral choices, just as we needed practice in the lab. **[11]**

The physicist Victor Weisskopf, who worked at Los Alamos as a young man, made an impassioned appeal in 1983 at a 40-year reunion of Manhattan Project scientists. He insisted that physicists have a "special duty" and must do what they can "to reduce the terrible threat that hangs over humanity." Reading a transcript of his speech reinforced my growing awareness that

> This task is much more difficult than the solution of scientific or technical problems, which requires only creative intelligence and technical ingenuity. The prevention of nuclear holocaust is much harder. It requires political and military insight, an understanding of the psychology of the adversary, a readiness to compromise and, most importantly, a great deal of wisdom. **[12]**

I found another partial answer to my question while reading a very poignant section in the book *Metamagical Themas*, where Douglas Hofstadter describes how it can come about that "good people" (like the mathematician Stan Ulam) may end up participating in "perilous projects." Hofstadter uses the metaphor of an ant colony as an illustration of how people come to participate in complex tragedies that unfold "as a consequence of their small actions joined with the small actions of many, many others." [**9**, pp. 388–9]

I collected the above examples while I was still an undergraduate. In graduate school I read about Alexandre Grothiendieck, a pioneer in algebraic geometry, who turned down prize money because he objected to practices within the mathematical community. His letter to the Royal Academy of Sciences of Sweden [**6**], which awarded him the Crafoord Prize, affected me deeply, and was an existence proof for me that there were those in my profession with the strength of their convictions, literally willing to put their money where their mouths were, to defend and uphold their ethical principles.

Educating for change

Owen Chamberlain, speaking at the University of California, Berkeley, on May 26, 1985, tells his own story of working on the Manhattan Project. For him, the lesson learned is the importance of reaching out to others, *as scientists*, urging the public to consider the ethical implications of research.

> I must reach out to the public beyond the lab and science lecture room. I must use my knowledge to make clear what the danger is, and use my credibility and experience as a scientist to help others use a scientific method to re-examine their beliefs—to consider all the facts, not just a chosen subset. [**4**]

I also wondered about our responsibility as scientists to speak out and act within the community of scientists, in order to affect the actual scientific work that gets done. In a letter written by J. E. Bernal that appeared in *Science* [**2**], I found an example of people working within the system, to emulate. For seven years, Bernal and his team had been conducting a diversity project in Colombia. As the genetic study progressed, they realized that many of their subjects were in the process of becoming extinct. They decided to redesign their project to include the broader needs of the people they were studying. They asked architects, designers, philosophers, musicians, artists, nurses and other faculty at Colombian institutions "to think of the enormous human diversity in Colombia and to suggest a research or care project they could develop." In the course of collecting their data, individuals received medical and dental care.

They also handled the dissemination of their data in a novel manner. Instead of publishing their results in scientific journals at once, they produced a series of books explaining their results in simple terms. They sent these books to the communities they had studied, as well as the Colombian institutions and the general public, hoping to generate knowledge and interest in diversity, identify problems, and help address their needs.

Conscientious objectors

Except for Grothiendieck (who continued to do mathematics, but withdrew from participation in the mathematical community), the stories so far have been about scientists or mathematicians who spoke out about ethical issues while remaining within their professions. I was three years into my first job as assistant professor of mathematics when I read in *Science* about a researcher who not only returned grant money, but also left his field of research because he came to feel he could not in good conscience continue to participate in the directions it was heading.

In 1994, John Fagan, a molecular biologist with nine years of continuous funding from the National Cancer Institute (NCI), returned more than $600,000 in grant money for research into cancer susceptibility genes because he no longer wanted to participate in genetic research. In the news conference where he announced his plans to return his latest grant renewal to NCI, Fagan called for a 50-year moratorium on releasing genetically engineered organisms into the environment, until further research into the long term consequences could be conducted. [**10**]

I also clipped an article from *The Women's Review of Books*, an interview with Dr. Martha Crouch, another scientist who renounced the research she was trained to do and now spends her time educating other scientists about the local and global impact of their work. Dr. Crouch was trained as a biologist and was using cutting edge molecular techniques in her research on embryo and pollen development in plants. This led her to consulting work for agricultural biotechnology firms. After reading an article in *New Scientist*, she realized that her work was related to a project on oil palm plantations and that these plantations were extremely environmentally damaging.

> I was horrified. I realized that I knew very little about oil palms and that most of what I was working on would be applied in systems I knew very little about. The idea of specialization and what that does to a sense of responsibility hit home. ...I decided to put my energies into areas that I felt would lead more directly to some substantive change in society. [**13**]

These scientists provide important models of conscientious objection. They refused to participate in practices that they believed to be harmful and wrong. Conscienscious objectors, especially those who quit when they have prestige within their fields, issue a wake up call to the rest of us to reflect on what we are doing. They follow Owen Chamberlain's dictum in doing the necessary work of educating others about the consequences of their research.

Teaching ethics

Many of you, like me, teach mathematics to future mathematicians and scientists. Examples like these inspire me to include discussions of ethical issues and human impacts of the work we do as part of my curriculum. My goal is not to indoctrinate students with my own values, but rather to help them become more alert in discovering ethical issues in their own lives. We may be disposed to act morally, but we may be unaware of ethical problems that lie hidden in the situations we confront. Or, we may not recognize that an ethical problem confronts us until we're too deeply enmeshed in a situation to extricate ourselves. (Recall the stories of Freeman Dyson and Stan Ulam.) However, with practice, we can learn to reason carefully about ethical situations.

While there are courses being developed and taught with titles like "Bioethics," "Engineering Ethics," and so forth, I'd like to argue for the importance of integrating ethics *directly* into mathematics and science classes. To make it clear that the ability to make reasoned ethical decisions is an important part of expertise in our respective disciplines, we must value it enough to actually devote some time to discussion of ethics in our classes, not merely rely on stand-alone courses that are not viewed by students as an integral component of their professional training.

If we agree that teaching ethics is not out of place in our classrooms, it is natural to ask *how* one might incorporate societal issues into a standard science or mathematics class. How much time should one devote to this? And where can one find the time in an already overloaded curriculum? I cannot offer any formulas[1] or prescriptions—indeed the answers to these and other questions will vary from teacher to teacher and even change from class to class and year to year. The first important step is to make a commitment, to oneself and one's students, to look for opportunities to inject discussions of ethical issues into your classroom experience. Once the awareness is there, openings present themselves.

I offer an example of how this has played out in my own classroom. One topic that always comes up is grades. When I remark that giving out grades is one of the most unpleasant tasks in my job, inevitably students respond with "OK, just don't give us grades!" At this point I stop and ask, what would be the consequences of this action? Who would be harmed? Who would benefit? And so forth. In just a few minutes, friendly banter has become a more serious discussion helping us identify issues and ask deeper questions.

Case studies

There is a habit of thought I try to inculcate in my students when teaching mathematics that applies here just as well: avoid simplistic generalizations or unexamined premises. To do this, one needs practice. How can one *practice* ethical behavior and decision-making?

Discussions of how to decide what constitutes ethical behavior often reach an impasse when participants claim "it's just a matter of personal opinion." One way to counter this view is to present students with various case studies along with a set of questions that guide them to identify ethical problems, define the issues at stake, list the options for action, and discuss the consequences. In discussing these actual or invented scenarios, students make their values explicit and examine them, sort out their arguments, and then apply their values in concrete situations. Analagous to applied mathematics, one might call this *applied* ethics. Indeed, there is something of a thriving "cottage industry" in applied ethics, and philosophers are working closely with scientists and educators to produce materials (case studies, video vignettes, and accompanying discussion guides and assignments) for use in undergraduate, graduate, and postgraduate training.[2]

Another issue of direct relevance in students' lives is cheating. And of course the values of honesty and integrity are equally crucial for future mathematicians and scientists in conducting their research. I encourage group work in my classes, especially on long projects I assign, but I also give take-home exams where I explicitly forbid collaboration. Due to some unpleasant experiences in the past, I now have students view a short video vignette called "The Take Home Exam."[3] In the scenario, one student finds the answers to a take home exam in a book in the library, and shares this information with some other students. The issues raised in the episode include loyalty, trust, confidentiality of information, and credibility of authority. Everyone in the video,

[1] Although I am more than happy to share the materials and ideas I have developed over the years with any interested readers. Just e-mail me.

[2] For example, see **[1]** for a report on some of these programs. Other resources to check out include: *Integrity in Scientific Research* is a series of five video vignettes available from the Program on Scientific Freedom, Responsibility and Law at AAAS, with web site at http://www.aaas.org/spp/video/video.htm; The Poynter Center for the Study of Ethics and American Institutions has a web site, http://www.indiana.edu/~poynter/index and gives yearly workshops; and Ethics Across the Curriculum is a program sponsored by the Center for the Study of Ethics in the Professions, Illinois Institute of Technology, Room 166, Life Sciences, Chicago, IL 60616-3793.

[3] *Academic Integrity: The Bridge to Professional Ethics*. Center for Applied Ethics, Duke University. The tape, which includes five vignettes, and workbook/instructor's manual is available for $50.00 from Aarne Vesilind, Department of Civil and Environmental Engineering, Box 90287, Duke University, Durham, NC 27708-0287.

including the professor, bear some responsibility for the uncomfortable situation that arises. During the discussion following the viewing, we all make our expectations explicit, and establish an atmosphere of mutual trust and regard. This small investment of time has done more to prevent cheating than all previous threats and punishments.

Infusion tips

What about ethical issues related to the actual subject matter we teach? Occasionally I teach an introductory course in statistics. This subject is rich in material that can lead to fruitful discussions. Here is a provocative example that raises questions about the use of statistical data.

Dr. Robert Pozos, director of the hypothermia research laboratory at the University of Minnesota, announced that he planned to use data collected by doctors at Dachau on concentration camp prisoners. The data included observations and physiological measurements on subjects placed in vats of freezing water. Responding to sharp criticism from scientists and Jewish leaders, Pozos explained that because mammals differ so widely in their physiological responses to extreme temperatures, this data could not be replicated with animal subjects.

> "We should under no circumstances use the information. It was gained in an immoral way," said Dr. Daniel Callahan, director of the Hastings Center, a medical ethics think tank in Briarcliff Manor, N.Y.
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> "I think it goes to legitimizing the evil done. I think the findings are tainted by the horror and misery," said Abraham H. Foxman, national director of the Anti-Defamation League.
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> Several medical ethicists contend study of the Nazi research could save lives and, if published with a condemnation of the methods, call attention to the plight of the Jews, Poles and Gypsies killed in the experiments.
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> Because the Egyptians used slave labor, "does that mean we should never gaze at the pyramids?" asked Dr. Thomas Murray, director of the Center for biomedical Ethics at Case Western Reserve University in Cleveland. [Associated Press, quoted in [**3**], fig. 7.1, p. 61.]

Asking students to take a stand on the issues raised in this article is one way of stimulating their moral imaginations.

This is an example of what has been dubbed an "infusion tip"—a short, thought-provoking topic, often based on a brief article, that leads to written and oral discussions. Just by scanning the daily newspapers, one can quickly accumulate a file of examples to stimulate brief weekly discussions of the use and possible abuse of mathematical methods and representations.

Exposing unexamined premises

There are many opportunities to engage students in discussions of ethical issues, if one is on the lookout for them. For instance, one might enlist the students in a project to uncover hidden values and biases already present in the seemingly neutral texts we use. Consider first this example from a textbook published in Germany, during WWII:

> *Problem 200.* According to statements of the Draeger Works in Luebeck in the gassing of a city only 50% of the evaporated poison gas is effective. The atmosphere must be poisoned up to a height of 20 metres in a concentration of 45 mg.

per cubic metre. How much phosgene is needed to poison a city of 50,000 inhabitants who live in an area of four square kilometres? How much phosgene would the population inhale with the air they breathe in ten minutes without protection against gas, if one person uses 30 litres of breathing air per minute? Compare this quantity with the quantity of the poison gas used. [**5**, p. 244]

This example may seem so egregious to us that we dismiss it as something that would never occur today. But it is a truism that we find our own hidden biases most difficult to detect. We move ahead a few decades to our own country, for the next example.

Robert Fogel, an economics professor at Harvard whose specialty is applying quantitative methods to economic history, co-authored a book called *Time on the Cross*, that caused quite a stir when it was published in 1974. The authors used statistical arguments and pages of computer data to "prove" that the slave system in the South was both more humane and economically more efficient than the free labor system that existed at that time in the North. The book and its purported results caused quite a bit of harm, until others studied the data and exposed errors, faulty inference, dubious assumptions, etc. For instance, Thomas Haskell, in his critique of the book, points out that "readers of *Time on the Cross* are inclined toward a benign view of slavery when they read that the average slave on the Barrow plantation received only 0.7 whippings per year." But, as he points out, the really relevant question is,

"How often did Barrow's slaves see one of their number whipped?"—to which the answer is every four and a half days. Again the form in which the figures are expressed controls their meaning. If one expressed the rate of lynchings in the same form Fogel and Engerman chose for whippings, it would turn out that in 1893 there were only about 0.00002 lynchings per black per year. But obviously this way of expressing the data would cause the reader utterly to misunderstand the historical significance of the 155 Negro lynchings that occurred in 1893. [**7**, p. 114]

The Bell Curve [**8**] provides a more recent example of a book that uses statistical arguments to draw controversial conclusions.

These examples seem obvious to us, and yet what do they have to do with what goes on in *our* classrooms? What about the exercises posed in the textbooks we use, questions that ask students to minimize costs, maximize profits, plot trajectories of missiles, find the angle of elevation that maximizes the range of a cannon, etc. Consider this problem from a standard calculus text:

An offshore oil well is located at point A, which is 13 kilometers from the nearest point Q on a straight shoreline. The oil is to be piped from A to a terminal at a point T on the shoreline by piping it straight under water to a point P on the shoreline between Q and T and then to T by a pipe along the shoreline. Suppose that the distance QT is 10 kilometers, that it costs \$90,000 per kilometer to lay underwater pipe, and that it costs \$60,000 per kilometer to lay the pipe along the shoreline. What should the distance be from P to T in order to minimize the cost of laying the pipe?

Notice that the sole measure of optimality in this picture is cost. What other factors might be optimized? How many decisions made by government agencies (often based on advice offered by mathematical consultants) use economics as the sole criterion for optimization? How could we mathematically model the environmental and human impact of laying this pipe? One might argue that for pedagogical and simplification purposes that the problem itself might need to remain the same. But we should at least be aware of, and question the implications of basing our decisions solely on economic factors.

Conclusion

My final story is about a bright student who confronted me with my own ethical conundrum. I had just given my little talk about how I wasn't trying to impose my own values ("I'm not trying to tell you *how* to think, I'm just trying to encourage you *to* think about these issues"). Suddenly a disgruntled voice said in a stage whisper that we all heard, "Bullshit!" Instead of scolding, I encouraged the student to elaborate. "I signed up for this course to learn math. You're imposing this ethics stuff on me." I stopped for a moment, and had to admit, "You're absolutely right." But, never one to let a teachable moment pass, I went on to say, "You've identified an ethical dilemma for me. I need some help from all of you to examine the consequences of my actions, to figure out who benefits, who's harmed, and to decide if I should change my behavior." In other words, I was able to model the very kind of thinking I was trying to teach.

Yes, it takes time to introduce these topics. Yes, the discussions can get heated and be difficult to manage. Yes, there is extra work to be done if one gives a written assignment. Sometimes I wonder if I can afford to take all this extra time and effort. Then I turn around and see the questions of my younger self mirrored in the minds and hearts of my students and know that I can't afford NOT to.

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