Integrating Ethics into an Undergraduate Control Systems Course

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When I first contemplated the idea of including ethics in a Control Systems course, it seemed a daunting task, since the lectures were already crammed tight with technical material. More importantly, since the course is a senior-level technical elective, the topics are rather abstract, making it even more difficult to establish linkages with real-world problems. However, as I began to ponder on this during the Ethics Across the Curriculum Workshop, it quickly became clear that an exposure to ethics could also provide the mechanism to make this material more concrete. So I began searching for a pertinent case study that would highlight the important ethical dimensions of control system design. After some searching, I found references for the BART case study from the 1960's, which involves Automatic Train Control for the San Francisco Bay Area Rapid Transit (BART) trains. In particular, several engineers had become concerned about the lack of fail-safe provisions in the control system, and they lost their jobs after publicizing their concerns. Suddenly, it seemed obvious that safety for the consumer of the technology had to be one of the design objectives for the control system.

Introduction to Ethical Issues

On the first day of class, I normally provide an introduction to feedback control systems and the technical objectives, which they are designed to satisfy. This time, I also put up a blank slide entitled "Non-Technical Objectives" and asked the class to suggest additional requirements on a practical control system. Here's the list that they provided:

- Safety to humans and animals
- Economical
- Communication/Coordination
- Durability
- Hardware constraints
- Environmental factors

Interestingly enough, the first item that they mentioned is also the first fundamental canon in the American Society of Mechanical Engineers (ASME) Code of Ethics. So I showed them the latest copy of the ASME Code of Ethics and suggested that many of the items that they had identified could easily be interpreted as ethical responsibilities of a control engineer.

This provided the springboard for discussing the BART case, which provided a graphic example of the potential safety ramifications of control system design. I showed them the picture of a BART train that had run off the track in October 1972, and suddenly the students could relate to the potential consequences of ill-designed control systems. I briefly discussed the reasons for the mishap and mentioned the concern of three BART engineers who eventually lost their jobs because of it. I would come back to this case later, but at this point, I had at least sensitized the students to the need to ponder broader ethical considerations in control system design.

Ethical Case Studies

Six weeks into the semester, we were ready to start designing real control systems, having covered all the necessary technical preliminaries. At this point, I felt it was appropriate to return to the BART case, but this time, I would actually present a real dilemma that the students would have to discuss and resolve. I therefore provided them with the following Ethics Case, inspired by real events:

> **BART Automatic Train Control Case**
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> You have been working for BART (Bay Area Rapid Transit) as a systems engineer for about 5 years. Although Westinghouse actually designed and built the Automatic Train Control (ATC) system, you have been intimately involved in testing early prototypes of the control system hardware and software.
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> After extensive testing, you discover that quite often, the low-voltage circuitry designed to detect a stopped train on the tracks fails to function properly. The result is an "all OK" signal to the next train that could cause a collision if no other contingencies are put in place. In fact, one such collision already took place shortly after public train service began.
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> You have alerted your immediate boss about this problem, but she has been too busy to really listen to your concerns. She thinks that since Westinghouse is in charge of designing and building the ATC, it is really not your business to second-guess their design choices. And, since they are aware of the problems, they are already working on a solution of their own.
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> Although you don't know the details of their design solution, you do know that it still involves low-voltage track circuitry. You are convinced that this scheme is doomed to fail, and only a high-voltage circuit will ensure reliable train detection.
>
> What should you do?

As the discussion ensued, I was struck by the students' apparent enthusiasm to engage in the dialogue. To guide the discussion, I put the Seven Step Guide to Ethical Decision Making (M. Davis, *Ethics and the University*) on the overhead projector. Many creative suggestions were made, including: "leak the problem to the press," "go over your boss," "try to persuade your boss to change her mind," "talk directly to Westinghouse," and "do nothing." As time ran out, I asked students to vote on their preferred choice. Interestingly, the majority of the students chose to try and persuade their boss of the need to pro-actively seek a better solution.

On the homework assignment that week, I added an item to the regular controller design exercises. In particular, I asked them to ponder the following issue for the design of an autopilot for a sailboat:

> "While testing your electronic controller with real hardware, you notice that, on rare occasions, the boat makes sudden large heading changes. After further analysis, you discover that the compass was sending out erroneous heading information. Since you have already signed off on your design to your boss, the order for the compass sensors has already been processed. What do you do? (Please provide 3 alternative courses of action and a reasoned discussion of how you arrived at your choice.)"

This exercise gave students an opportunity to apply the in-class discussion to an issue relevant to their controller design. In the process, many of them invoked the ASME Code of Ethics as a guide to the importance of ensuring the public safety.

During the last week of the semester, I once again presented an Ethics Case, this time focusing on the Airbus autopilot:

Airbus Autopilot Case

You have been working for Airbus as a control systems engineer for about 1 year. After spending time mainly coming up to speed, you have just been asked to solve some problems on the autopilot software for commercial Airbus jets.

The software has been designed to perform many functions previously performed by the human pilot. Besides speed and heading control, it also tries to assess current conditions and makes decisions to improve current performance.

Early reports from airline pilots suggest that under certain conditions, the autopilot performs control actions that actually can cause the plane to stall and potentially crash. Only quick thinking by the pilots has saved the aircraft in the past.

You have been asked to figure out what's going wrong. However, in the meantime, planes are still flying with the installed software, posing the risk that a fatal crash is only a matter of time.

What should you do?

This time, the discussion was quite spontaneous, and it appeared as if the students were anxious for another opportunity to ponder these issues. They generated even more choices for this case, including: "write memo to airlines not to use autopilot," "add code to make autopilot fail-safe," and "make pilots aware of proper and safe operation of the autopilot." When asked to decide on a course of action, the majority of students chose the last option, thereby delicately balancing safety with the need to maintain company credibility.

Design Project

Each semester, students are asked to develop a solution to a major control design problem as a final project. This semester, it involved stabilizing an inverted pendulum by controlling the motion of the cart that supports it. Students worked in teams of three to model the mechanism, design a control strategy, and then implement it on the actual hardware and software platform. This time, however, I added another requirement in addition to the technical requirements: Practical Considerations, which meant students had to consider safety issues and design strategies for ensuring fail-safe operation. In the process, several of the design teams came up with fail-safe strategies to ensure that the motor would shut off well before the cart reached the end of the track.

Conclusion

In the surveys that I distributed at the end of the semester, a majority of students felt that this course increased their awareness of ethics issues (20/21), changed their understanding of the importance of professional ethics (13/21), and increased their ability to deal with ethical issues (18/21). Most of the students that did not see a change in their perceived importance of ethics commented that they already recognized its importance (6/8). Even more importantly, a majority of students felt that the amount of time spent on ethics in this course was about right (18/21), with the rest commenting that a little more time might have been spent discussing a few more case studies and evaluating potential decisions. Some typical student responses:

- "It gave specific examples of ethically challenging situations that have occurred in the real world and asked us to analyze and think of possible actions."
- "It changed my understanding by showing that not all ethics decisions are cut and dry."
- "It helped develop thought process to come up with options."

As for me, I thoroughly enjoyed researching the individual case studies and discussing them in class. In the process, I was still able to cover the technical content, but I think now the students have a better, more practical feel for controller design. Although I was skeptical at first about whether mini-ethics lessons would work in my course, I must say the results suggest that it can indeed be done successfully, with positive outcomes for both students and instructors. I intend to introduce similar ethics components into my other courses next semester.