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Risk Management and Ethics in Capstone Design

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Abstract

Engineers make ethical decisions all the time in solving design problems, which is the intellectual core of engineering. They need to make those decisions and the grounds for them explicit. Careful examination of a course's syllabus can reveal how the ethical considerations already there can be made explicit. The Ethics Across the Curriculum (EAC) program at the Rochester Institute of Technology (RIT) was designed to bring together faculty from diverse disciplines across the university, who would then spend time examining their syllabi, and seeing how ethical considerations could be made explicit or naturally introduced as an integral part of the course, not as an add-on. One of the engineering areas targeted was the college-wide senior design course sequence, since 80-90% of the college's graduating seniors enroll each year and improvements here affect nearly all of the graduates (Biomedical, Computer, Electrical, Industrial, and Mechanical Engineering).

Risk management has been identified as a natural avenue for incorporating ethics into senior design. Prior to the instructor's EAC participation, the focus of risk management instruction was on technical and resource risks that could prevent the team from completing their project. That focus often had little bearing on the use of their product or process after it is handed off to the customer. This is therefore not necessarily indicative of ethical considerations. After EAC participation, new instructional content has been created that highlights five risk categories that extend the consideration of risks beyond the completion of the project: technical, resource, safety, societal, and environmental risks. When teams consider safety, societal, and environmental risks, they have considered, at least at a cursory level, the harms that their decisions may cause and how a redesign could mitigate or remove those harms.

The questions the authors seek to answer are: (1) Were students able, after seeing examples, to consider risks related to harms that their designs may cause? (2) Did the balance of risks related to technical and resource challenges, compared with risks related to harms that could be caused, vary depending on the type of project examined? And (3) where are the opportunities for improvement in integrating ethics into risk management in the senior design sequence? This paper includes a review of risks identified by senior design teams before and after revision of the instructional module on risk management. After the revision, the overall number of risks teams identified did not change, but a higher percentage of the risks identified were related to safety, societal, and environmental harms. Both before and after the revision, risks were compared across different project categories. Before the revision, teams working on projects for industrial sponsors identified the highest percentage of their risks as social or environmental.

Ethics across the curriculum

Engineering faculty have an obligation to prepare their students for the ethical practice of engineering. An obligation to "hold paramount the safety, health and welfare of the public" is prominent in the Code of Ethics of many engineering professional organizations (e.g., AIChE, ASCE, ASME, IEEE, NSPE). The College of Engineering at RIT has laid out an ethics curriculum for its students, which includes senior year objectives of being able to (1) explain ethical behavior in a team environment, (2) summarize how to build and maintain a professional reputation, and (3) *recognize the complex relationships that exist between engineering decisions and their broader impact*. While items (1) and (2) are addressed several times in the undergraduate curriculum prior to the senior year, item (3) is not. It was the focus of the capstone instructor's participation in an Ethics Across the Curriculum (EAC) initiative launched by the Chair in Applied Ethics in the Department of Philosophy. Ethics as it relates to engineering decision making and the related effects is addressed in the risk management requirement of senior design. Since the senior design projects all have real clients, and involve real prototypes or process implementation, risk management is a real concern for the teams. This provides the added benefit of integrating ethics into existing course material rather than treating it as a standalone topic. This practice addresses a known challenge with ethics education [1], [2], and has been recommended in the literature as far back as 1996 [3].

Risk management in capstone design

Risk management in engineering senior design at the RIT was traditionally presented as a way to anticipate what could go wrong. Instruction in class was focused primarily on risks related to technical feasibility and the resources required to complete a project. Teams used a standard template that addresses risk, cause, effect, likelihood, severity, and proposed action. Each capstone team is required to assess and manage risk throughout their project. As teams progress through the two-semester sequence, they are expected to report out on the status of their risk management at each formal design review/prototype demo – eight times total. Risk updates are done alongside progress vs. project schedule, design/prototyping/testing updates, and problem tracking. Students are encouraged throughout the course sequence to focus on the connection between these deliverables: How is risk management driving design decisions? How is the prototype progress affecting your schedule? How are design decisions affecting the identified risks?

Prior to the instructor's EAC participation, students completed an in-class workshop on risk management that included an exercise where students observed an activity and identified ways in which the planning team practiced risk management, with a heavy focus on technical and resource risks. These risks are the ones that could prevent the team from completing their project, but they have little bearing on the use of their product or process after it is handed off to the customer and are therefore not necessarily indicative of ethical considerations. As outlined in [1], this type of instruction is typical of technically-focused risk management exercises, which are common in the engineering education community in, for example, Electrical [4] and Construction Engineering [5], and Engineering Management [6].

Ethics in risk management in capstone design

In the capstone course, students are engaged in projects representative of the sort of work they will do after they graduate. So seeing how ethical considerations enter into planning and completing a project will hopefully carry over into their professional lives. The faculty chose to see how they could get students to incorporate ethical considerations into their risk management activities. By incorporating ethics into an integrated course requirement, the students will be in a position to see a more meaningful connection between ethics and the practice of engineering as compared with a stand-alone ethics course or module, an isolated case study, or an abstract discussion that does not require students to take action related to real potential harms. The normal risk analysis involves their identifying, analyzing, and taking action on the risks that may negatively affect the completion of their project – risks that have an internal *cause* and *effect*. But faculty can ask them to broaden that analysis in three ways.

First, students are somewhat isolated from the kinds of risks that they will face once they graduate and are employed, and so when they focus on the risks to completing their project, they focus on those internal to the project — how to handle team dynamics, or how to complete a complex analysis or get a prototype built in a timely manner. But faculty ask them to broaden their view by considering risks that have a *cause* external to their project, over which they have little if any control. These are risks the students will face once they are employed. Crucial members of their team may be reassigned, or management may cut the project's budget. In class, students face analogues of such risks because they are effectively working under contract with individuals and companies to solve problems they have. Teams may experience scope creep, and they may work with clients who fail to respond sufficiently to queries from the team. Asking students to consider risks with external causes will ensure that they do not just focus on matters over which they have control, but also consider how to deal ethically with any adversity that they may encounter. This aspect of risk management is already practiced by most teams as they realize that the realities of external factors can prevent them from completing their projects.

Second, teams can consider the risks associated with their completed project: risks with external *effects*. Is it easy for consumers to use? Is there anything about the product or process they create that can cause harm to those who use it? Are there social costs to introducing the artifact? Can their decisions have an impact on the environment? How can these harms be mitigated?

Third, whether the causes and effects of the risks they identify are internal or external, faculty are asking them to consider the ethical aspects of the risks. The easiest way to ensure teams do that is to ask them to identify and assess the harms involved in the risks. Since it is a moral principle that we should never cause unnecessary harm, their identification of the harms requires that they see if there is a way of preventing or reducing the likelihood or severity of the harm. For example, a student who fails to contribute to a project is a very real resource risk with significant internal impact. *Mitigating* that risk is also an ethical enterprise: how can the rest of the team and the faculty fully engage a team member who is already at odds with other members of the team, and how are they to do that in a way that allows all the members of the team to emerge from the difficulty with their dignity intact and a renewed willingness to complete the task as a team? Failure to consider the ethical aspects of risks, in terms of cause, effect, or mitigation strategy puts us at risk of not preparing students to be aware of the ways in which unethical decisions are made [6].

The new instructional content is an online module where students watch videos from, or related to, prior senior design teams at RIT and then identify risks for the example projects and then for their own project in each of five specific categories: technical, resource, safety, societal, and environmental risks. Teams are also instructed to identify the action they will take: prevent, reduce, transfer, or accept the risk. These instructions are shown in Table 1. Teams that identify safety, societal, and environmental risks have considered, at least at a cursory level, the harms that their decisions may cause. While the ideal is to help students broaden their analysis in each of the three ways indicated, faculty have begun only by asking students to identify and assess risks related to safety, societal, and environmental harms. This is the first step toward practicing ethical risk management, as defined in [1]. The next steps in this work are outlined in the final section of the paper.

Table 1: Risk management instructions provided to students.

Categories of Risk - these are examples of the sorts of risks that might fall into each category	
Technical	Scope creep, components do not work as expected, team members lack the skills necessary to do the work, as-fabricated parts differ from design, flawed assumptions
Resource	Schedule (e.g.: parts do not come in on time, machine shop is busy), personnel (e.g.: team member gets sick, travels for an interview), cost (e.g.: components cost more than expected, fabrication must be outsourced), facilities (e.g.: specialized piece of equipment fails, lose access to lab)
Safety	Injury to team, injury to end user, damage to equipment
Environmental	Team must dispose of significant excess material, design requires hazardous materials, selecting a low-cost component that could lead to shorter life and the need for additional purchases, design requires purchase of consumable items for end user
Social	Design choices cause harm to a team member or end user based on social issues (e.g.: loss of confidentiality, contradicts local cultures and customs)
Action taken – how will the team will address (or not) the risk	
Prevent	Action will be taken to prevent the cause(s) from occurring in the first place.
Reduce	Action will be taken to reduce the likelihood of the cause and/or the severity of the effect on the project, should the cause occur
Transfer	Action will be taken to transfer the risk to something else. Insurance is an example of this. You purchase an insurance policy that contractually binds an insurance company to pay for your loss in the event of accident. This transfers the financial consequences of the accident to someone else. Your car is still a wreck, of course.
Accept	Low importance risks may not justify any action at all. If they happen, you simply accept the consequences.

Goals and questions

This paper focuses on two specific elements of ethical risk management. First, did students practice ethical risk management by considering the harms regarding safety, for instance, that their decisions may cause? In other words, did an instructional change that specifically highlights categories of risks that relate to potential harms result in more teams practicing ethical risk management? Second, do some teams tend to consider harms more thoroughly than other teams because of the nature of the project they are pursuing? Some of the projects have a strong focus on human involvement, e.g., biomedical devices for people with disabilities and technology for people in developing nations. Are students working on these types of projects more likely to consider the harms they may cause for the end user?

Methods

All capstone teams in the program are required to keep an online archive of their project materials, including all technical documentation, project management documentation, and final publications. Teams start with a blank version of this archive, which contains a file structure and templates for standard documentation, including Risk Management. Each team archive in the fall-spring cohort from 2014-15 ("before" group) and from 2015-16 ("after" group) was examined, and the Risk Management document downloaded. Most teams continually update this document, and as risks are addressed or become irrelevant, they reduce the likelihood and/or severity to 1 or 0 so that the final Risk Management document contains all risks the team considered over the course of the year. In cases where teams retained more than one risk document and those documents were different, the risks from all documents were considered. The limitations to this approach are that (1) some teams failed to post their document in a location where it could be found and (2) some teams may have removed risks from their document if they were considered irrelevant and those risks would not have been counted.

In the "before" group, teams were not required to identify risk categories (e.g., technical, safety, etc.), and that categorization was performed by one of the authors in accordance with the descriptions in Table 1. In the "after" group, teams did have a place on their Risk Management Template to identify risk categories. Most teams filled this column out, and where they did not, the same author identified a category. In reviewing the pool of "after" documents, it was clear that some risks were categorized incorrectly. For example:

- Risk: Poor team dynamics collaborating with team XXXXX
- Cause: Two teams are working together to accomplish different tasks on the same [hardware]
- Effect: Confusion and difficulty implementing team's functionality to [hardware].
- Category: Social

In reality, this is a resource risk since the effect would be that the team lacks sufficient access to the hardware to work on it, and it was re-categorized as such.

In other cases, risks could reasonably be put into multiple categories. If the team identified a category that was a reasonable fit, it was left there. For example:

- Risk: Voltage from power supply too high
- Cause: Not checking to make sure components are compatible with each other
- Effect: Device can explode
- Category: Technical

Since a high voltage state would be an error due to a technical failure, the team legitimately considered this a technical risk. Since the effect could have been harmful to the user, this could also have been considered a safety risk, but the team's logic was allowed to stand.

Results: Examples of risks

A detailed look through student risk assessment revealed some interesting observations, and a representative example of each is shown here. Where necessary, clarifying information from the project is included [in brackets].

1. Some teams identified resource risks that require ethical decision making.
   - Risk: "The team experiences any internal conflicts"
   - Effect: "Tasks may be delayed"
   - Strategy: "We will refer to the team Norms and Values and Roles and Responsibilities to resolve the conflict"

2. Some teams identified safety risks that would affect the team, not just the end user. This is still a consideration of the harms that may occur although it is a risk that could prevent the team from completing the project.
   - Risk: “Unsafe testing during prototyping”
   - Risk: “[Team] member is injured while machining prototype”
3. Some teams do not take all risks seriously even when considering risks that happen on a fairly regular basis.
   - Risk: “Team member(s) drop the class, not enough manpower to complete the project”
   - Strategy: “Transfer: drink more to transfer the risk to your liver”
4. On the other hand, to their credit, teams insightfully considered the potential harms that their decisions could cause. Even though these risk categories are now required, teams did more than identify token risks, or make light of the requirement.
   - Risk: “Process changes for the operator create changes in their norms, possibility of operators rejecting new design”
   - Risk: “Tank location [for growing nutritional algae] could have been used for [necessities such as] housing, [stable] crops, [stable] livestock population”

Results: Effects of instructional change

Both the number and types of risks identified by teams were tallied. Overall, the teams found about the same number of risks before and after the instructional change (Figure 1). There was no statistically significant difference in the mean or variance in the number of risks found per team, on average. The instructional change did not result in students identifying *more* risks.

When the types of risks were tallied, however, there was a clear difference. For this study, one author looked at a simple distinction between Technical/Resource risks, which typically derive from risks that will prevent the team from completing their project, and Safety/Social/Environmental risks, which typically relate more to the harms that could be caused as a result of the team’s decisions. While approximately 10% of the “before” group’s risks were

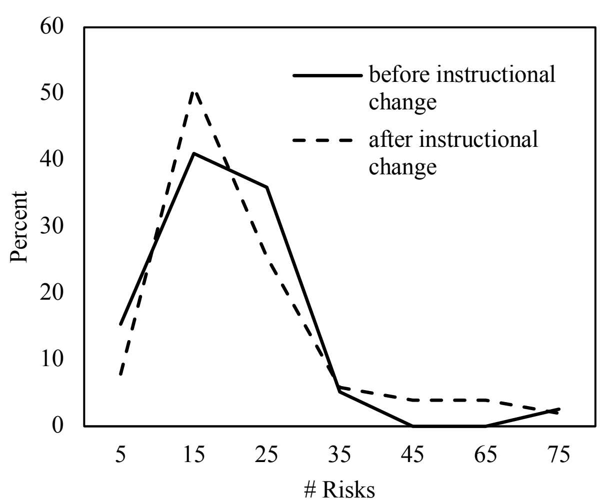

Figure 1: Histogram showing that the distribution of the number of risks found by teams was similar before and after the instructional change.

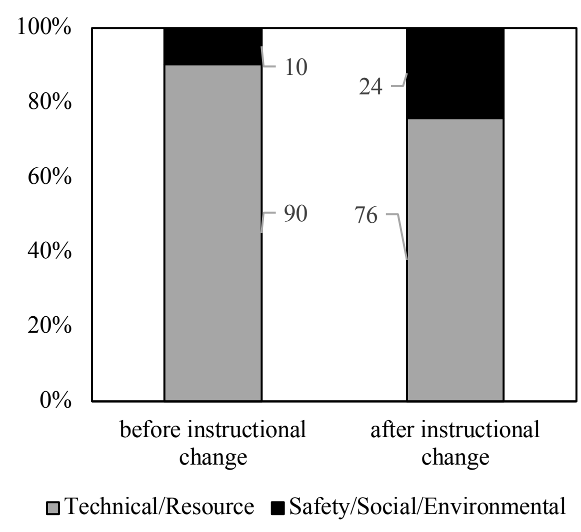

Figure 2: A higher percentage of teams’ risks were Safety/Social/Environmental risks after the change.

related to potential harms, nearly 25% of the "after" group's risks fell into this category (Figure 2). Although the students did not identify *more* risks after the change, they were clearly giving more thought to risks that had an effect beyond the scope of their work on the project, which is a first step toward practicing ethical risk management.

Results: Risk assessment by project type

In addition to comparing the effect of the instructional change across the entire class, the types of risks identified by teams in different project categories were also examined. Table 2 shows the breakdown of projects across these categories. There was no consistent pattern in the number of risks identified by each team, either increasing or decreasing, but this may be due to the small n's for some of the categories. The categories used for this analysis were:

- Industry = projects with external sponsors with commercial interests
- Biomed = biomedical and assistive devices
- Education = projects to develop educational tools
- Dev nation = technology for use in developing nations
- Research = projects to develop research tools, primarily for faculty
- Robots = robotics projects
- Aero/Vehicle = projects related to air, water, or land vehicle development. This project includes students from competition teams (FSAE, Baja, etc.)

Table 2: Distribution of teams across project categories, and average number of risks identified

	Before Instructional Change		After Instructional Change	
Category	**# Teams**	**Ave # Risks/Team**	**# Teams**	**Ave # Risks/Team**
Industry	6	20	14	24
Biomed	7	13	5	28
Education	3	23	8	16
Dev Nation	5	23	7	17
Research	14	20	6	11
Robotics	2	25	6	23
Aero/Vehicle	2	12	6	26

When looking at the type of risks identified by teams in each category, a clear trend does emerge (Figure 3). In all categories except aero/vehicle the distribution of risks was skewed much more heavily toward Technical/Resource risks, with more focus on Safety/Social/Environmental risks after the instructional change. The aero/vehicle category included only two teams during the year before the instructional change, and all of their Safety/Social/Environmental risks were in the Safety category.

Looking in further detail at the percentage distribution across risk categories (Figure 4), it is interesting to note that, while the occurrence is still low, industry-sponsored project teams were the only ones to consider environmental risks *prior* to the instructional change. The percentage of combined social and environmental risks identified by industry-sponsored project teams *prior* to the change was also higher than that of teams in other categories, although teams working on biomedical devices did consider more social risks. In all cases, safety-related harms are the most commonly identified, and prior to the instructional change, these were the only harms that some teams considered. After the instructional change, all teams were able to consider meaningful harms in each of the risk categories outlined, and there was no evidence of teams identifying "token" risks just to check the box that they did their required assignment.

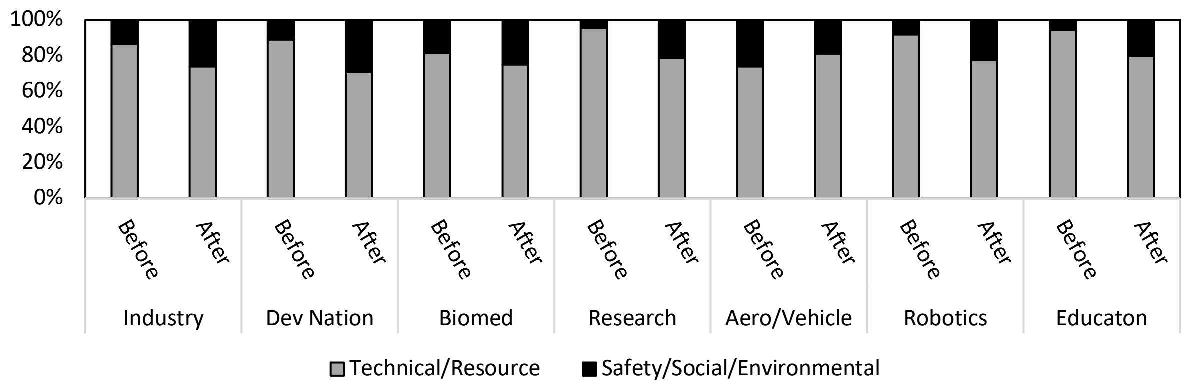

Figure 3: The effect of instructional change was observed in all project categories except aero/vehicle.

Discussion: Are students practicing ethical risk management yet?

In general, students are very thorough when considering risks that have a direct effect on themselves and their ability to complete their projects. Given the constrained nature of a capstone design class, this is not surprising. Some of those risks are related to harms that may be caused (to the team), which is reassuring. However, these results show that with a slight instructional change, faculty have begun to open students' eyes to consideration of the *external* effects of their design decisions beyond the bounds of their class.

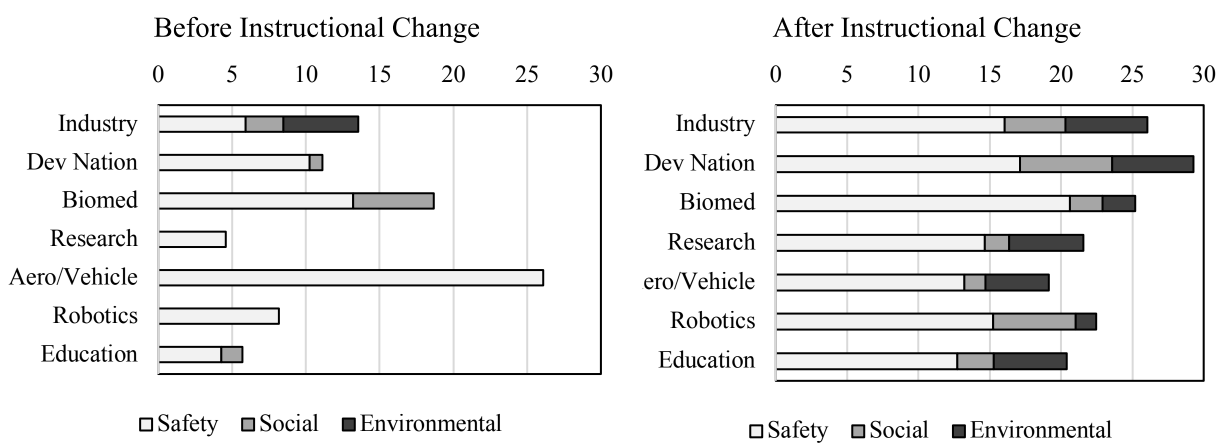

Figure 4: Percentage of Safety/Social/Environmental risks across all project categories, before and after the instructional change. The balance of risks not accounted for are Technical and Resource.

Readers can draw an interesting comparison between the risks identified by teams working with industry and teams working on technology for developing nations. Even prior to the instructional change, industry-based projects included more consideration for social and environmental risks. One possible reason for this is that industrial clients are expected or required to practice ethical risk management, and they passed this expectation on to the students by raising team awareness of potential harms whereas clients in developing nations did not. Alternately, the harms may be known, but outweighed by the potential benefits of the project, making the clients reluctant to raise the issues in what could be perceived as a zero-sum game. Either way, the fact that all categories of projects show improved awareness of harms is a step in the right direction toward practicing ethical risk management.

Next steps

As outlined at the start of this paper, getting students to focus on the harms their decisions may cause is only one step toward broadening their view of ethics in risk management in capstone design. Once these harms are recognized, faculty can work with students to consider how to deal with potential harms ethically, as well as how to judge when those actions are the responsibility of the team and when they should be transferred to the client or end user. The next step in supplementing instruction in risk management in the senior capstone course is to focus on the actions the teams recommend. Since the senior design projects result in real prototypes or processes delivered to real clients, even a list of thoughtfully generated actions for the client to reduce or remediate potential harms is an important part of a project handoff.

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