EMPOWERING ENGINEERING STUDENTS IN ETHICAL RISK MANAGEMENT

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Abstract – *The purpose of our study is to assess to what extent engineers are empowered by their professional training to engage in ethical risk management. Using the concept of self-efficacy and the results from a questionnaire answered by 200 engineering students, we suggest that the present engineering education fails to induce such empowerment.*

We therefore propose an innovative method to help in this matter. Carried out through workshops with 34 students, the efficiency of this method has been evaluated using group interviews and questionnaires. Our results suggest that such an approach is efficient, at least in the short run, to motivate students to engage in ethical risk management. Maybe more importantly, it triggers reflectivity on what it means to be an engineer today, a first step in engaging into the ultimate Grand Challenge of self-knowledge.

Keywords: Engineering education, ethical risk management, self-efficacy, empowerment, reflectivity, self-knowledge.

1. INTRODUCTION

The modernization of our society has been made through the development of advanced and complex technologies and processes, showing potentially high level of risks and uncertainties. As engineers are key actors in the design and development of these technologies, they have created methods to manage industrial risks. However, in spite of these sophisticated tools, the negative impacts of industrial activities are more than ever present, from global climate and ecological changes to more local and, unfortunately, recurrent disasters.

Several studies have shown the complexity and the profound ethical dimension of industrial disasters [see, for example, 9, 13, 16, 42, 48]. As well, numerous authors have criticized the ethical limits of the traditional deterministic approaches of risk management used in engineering, especially regarding complexity [e. g. 7, 16,

27], the necessity for collaborative and participative risk identification and assessment [e. g. 11, 20, 35], as well as the role of emotions [e. g. 37].

Are these limits inherent to the general mindset and sentiments with which engineers are trained to solve problems? Indeed, professional training, which influences group identity and membership, certainly affects the general professional behavior and especially ethics practices. More precisely, professional education may entail fragmentation, which has the potential to narrow ethical perceptions and to lead to questionable ethical reasoning and practices [17].

This issue of fragmentation for the engineering profession is well identified in the literature. For Richter and Paretti [36] for example, the profession suffers from disciplinary ethnocentrism¹. In their case study, they have observed that many engineering students “fail to understand the value of multiple perspectives and approaches [...] [which] limit individuals’ ability to integrate and synthesize differing epistemologies and value systems in addressing complex problems.” This failure, strengthened by their education, limits their capacity to address issues with different points of view or to collaborate with individuals having different perspectives.

The same observations can be found in the work of Downey [14], for whom engineers become multidisciplinary despite their training rather than because of it. Moreover, because of their identity of technical problem solvers, the focus of engineering education is essentially on the technical aspect of a problem, while rejecting or omitting the complex human dimensions of problem definition and solving. For Downey, as well as for Richter and Paretti, part of the solution may come from interdisciplinary integration in the engineering curriculum.

¹ In their study, Richter and Paretti use the term disciplinary “egocentrism”. We believe however that this behavior is placed at the group level, and influenced by a group identity. To highlight this, we use in our work the term disciplinary ethnocentrism rather than egocentrism.

Addressing this issue, Bucciarelli and Drew [4] have recently offered reflections and made specific suggestions to develop humanities and social sciences in engineering education. Such propositions address directly the question of fragmentation as well as the need for engineers to realize the limit of their knowledge and the need to interact with other experts [25]. It also highlights the difficulties to integrate humanities and social sciences in engineering education programs [23]. As well, connecting specifically interdisciplinarity and safety, Knowles [26] has presented Disaster-STS (science and technology studies), a field for social science, humanities and engineering to meet regarding risk management.

Therefore, our study aims to first answer the following research question: To what extent the present engineering education empowers students to engage in ethical risk management? Our results, based on a questionnaire, suggest that the present engineering education fails to induce such empowerment. We therefore propose an innovative method based on active-learning to help in this matter. We believe that this study offers a significant contribution to a critical question, as the nexus between risk management and ethics is clearly underdeveloped in engineering education [18].

2. ETHICAL RISK MANAGEMENT, EMPOWERMENT AND SELF-EFFICACY

2.1. Ethical risk management

What do we mean, in this article, by ethical risk management? Considering the diversity of perspectives on risk and in ethics traditions, it is certainly vain to try and give a univocal definition of what it should be. Indeed, as it will be shown hereafter, various authors have contributed to the development of ethical approaches to risk management. Therefore, we have considered for this paper that foremost, ethical risk management *is not* a rejection of traditional risk management *per se*. It is rather a process of questioning of these methods regarding the limits aforementioned and what they imply, based on three ethical traditions or perspectives: *the ethics of complexity*, *the ethics of dialogue* and *the ethics of moral emotions* which are, at the same time, distinct and interconnected.

Deterministic and reductionist approaches of risk assessment are mostly based on the decomposition of a system, on its modeling and on a cause-consequence linear chain analysis of the failure of individual components (technical or human), making them inadequate when considering complex systems [27]. Indeed, industrial organizations are complex living sociotechnical systems which evolve through non-linear interactions within themselves and with their environment. These notions of evolution, non-linearity, boundaries,

interactions between technical and non-technical dimensions, are, among others, key challenges when considering the safety of systems [19]. They are at the base of the complexity science which considers that a complex socio-technical system – for example, an industrial organization – cannot be fully and permanently understood, as they always show uncertainties as well as ambiguities [49].

These uncertainties and ambiguities necessarily bring a moral dimension in risk management [45] that we address through the *ethics of complexity* developed mainly by Cillier [see 7]. Such an ethics calls for modesty, responsibility and time of reflection when facing complex systems for we cannot perfectly understand and control them. This is not without reminding the precautionary principle, which, however, without an acceptance of uncertainties and responsibility, can eventually lead to inaction [47]. Indeed, as Cilliers and Preiser [8] have written: “The lack of complete knowledge does not mean that we should not act, but it does mean that we should do so with modesty [...]. Every decision should be the result of careful and critical reflection [...] and should unfold in time, neither too quickly nor too slowly.”

Also, because of ambiguities – the possibility of multiple interpretations of a situation – the ethics of complexity also ask to be sensitive to, and critical of, the diversity and difference of opinion and concerns from any stakeholder affected by the system [8]. Such a commitment is, for example, certainly reachable through dialogue.

Indeed, the *ethics of dialogue* is based on the acknowledgment of the otherness and the valorization of the diversity of perspectives. It aims at a mutual understanding and allows at revealing basic assumptions on a matter. This ethics has been operationalized in risk management through the notion of deliberative risk assessment. This approach acknowledges the diversity of perceptions of risks and valorizes non-expert inputs from stakeholders or from the civil society during the decision-making process [46]. Such a deliberative approach is also valuable for risk identification and communication, as the public may have a specific knowledge that experts have not [6], or inversely, that can be distorted by social amplification [24]. As argued by Renn [35], deliberative risk identification and assessment is therefore a “productive way of ensuring competence, fairness, and efficiency.”

This cooperative perspective on risk assessment is based on the rejection of the dilemma that experts have a scientific objective opinion on risks while public perceptions are biased and emotional, therefore perceived as irrational [20]. In this field, Slovic [e.g. 44] has largely contributed to highlight the importance of taking into account public’s perceptions and considering the interaction of reason and emotion. Therefore, a

deliberative risk identification and assessment, in addition to acknowledging multiple perspectives on risk, is not limited to cognitive reflections but also involves an emotional-ethical inquiry which “reflects a broader perception of risk that also includes important ethical considerations” [37]. Therefore, emotions are necessary to ensure ethical risk management.

Thus, using an *ethics of moral emotions*, Roeser [38] has argued that emotions, such as empathy and compassion but also fear and disgust, are indispensable in judging the acceptability of risks, especially regarding well-being, justice and autonomy. She has argued that such emotions are a primary source of ethical reflections over risks peculiarly relevant for the work of engineers. Indeed, engineers “should not be unemotional calculators; [...] they should work to cultivate their moral emotions and sensitivity, in order to be engaged in morally responsible engineering” [38].

Although other ethics theories or traditions, such as the virtue ethics or the ethics of care are important in risk management [see 40], we believe that the three perspectives presented before offer an adequate ethical frame as they address directly the limits of traditional risk management methods used in engineering and discussed previously. However, this frame is still insufficient to evaluate individuals’ engagement in this process of questioning.

2.2. Empowerment and self-efficacy

Conlon and Zandvoort [10] have argued that the most present and most developed individualistic approach used to teach engineering ethics fails to empower students. Indeed, because of its inconsistency with the complex context in which engineers will later evolved, this approach limits their capacity to engage and promote ethical reflections and safer practices for the society and the environment.

The effects of personal empowerment are strongly influenced by self-efficacy, as suggested in the work of Ozer and Bandura [33]. The theory of self-efficacy developed by Bandura stipulates that individuals who have a higher perception of their self-efficacy for a given action (the belief – true or false – that they are able to effectively achieve such action) are more likely to set up for themselves higher goals and have a higher engagement and motivation in the realization of this action [see 1, 2]. Based on this theory, we believe that students with higher self-efficacy in ethical risk management will be more motivated to engage in such approach when they will be practicing. Engineering education should thus empower students by enhancing their perception of self-efficacy.

Therefore, we propose to answer our research questions in three steps: 1- to assess, using a questionnaire based on the ethical frame presented before, the influence

of engineering education toward approaches in risk management; 2- to evaluate, using a questionnaire based on the concept of self-efficacy, the degree of empowerment of engineering education regarding ethical risk management; and 3- to propose and evaluate an innovative active-learning method to promote an ethical approach to risk management in engineering.

3. METHODOLOGY AND SAMPLE CHARACTERISTICS

3.1 Empowerment effect of engineering education

As introduced before, the concept of self-efficacy was used in this study as a proxy for empowerment. May and collaborators [29] have recently used this concept to assess the effect of business ethics training and have suggested that such training induces positive increases in moral self-efficacy. Therefore, a 10-item scale (see Table 1), based on their work as well as on guidelines from Bandura [3], was used to assess ethical risk management self-efficacy. All first- and final-year bachelor students from a major Canadian engineering school were invited through email to answer an online questionnaire and were asked to rate their confidence in their capability to perform each of the task on a 5-point Likert scale from 1- no confidence at all to 5- extremely confident.

Raw answers were received from 659 students over 1832 who have been contacted, representing a response rate of 36%. However, only 200 answers were complete and usable, for a final response rate of about 11%. Table 2 presents the demographic characteristics of the respondents. An analysis of variance (ANOVA) using STATA analysis software as been conducted to test the level of significance of the observed differences of ratings.

Thanks to the support of the chemical engineering department’s direction, this project has been presented in first- and last-year classrooms. This might explain the high participation rate in chemical engineering. The relatively high response rate in civil and mechanical engineering can be explained by the traditional importance given to risk management in these specializations. However, this heterogeneous distribution does not allow for comparison between specializations.

3.2 Active-learning method

To try and empower students to engage in an ethical approach of risk management, an active learning approach was selected in this study for it has been suggested to be an efficient educative method in engineering [see 15, 34]. Three different workshops, based on the ethical frame

discussed before, were developed. The idea with these workshops was for the students to confront situations, or be sensitized to aspects, closer to what they will experience later in their career, in a more active and immersive way than traditional teaching.

Table 1. Self-efficacy scale for ethical risk management

1. Analyze a system (industrial structure, process, etc.) to assess industrial risks.
2. Recognize ethics issues regarding risk management in engineering.
3. Recognize the interdependency of technical and non-technical dimensions in industrial risk management.
4. Recognize the need to integrate non-technical aspects in industrial risk management.
5. Use the role of emotions to enhance industrial risk management.
6. Analyze the limits of technical approaches in industrial risk management.
7. Recognize the transdisciplinary nature of industrial risk management.
8. Formulate technical AND non-technical strategies to enhance industrial risk management.
9. Use divergence of opinions about a risk to enhance its assessment and management.
10. Formulate strategies to reduce resistance about non-technical approaches in industrial risk management.

Table 2. Demographic characteristics of the respondents

Engineering Program	1 st year			4 th year		
	W	M	Total	W	M	Total
Aerospace	2	2	4	1	3	4
Biomedical	1	1	2	3	3	6
Chemical	20	15	35	18	21	39
Civil	2	3	5	6	12	18
Mining	0	0	0	0	0	0
Electrical	3	2	5	2	2	4
Geological	1	0	1	0	2	2
Industrial	1	3	4	3	6	9
Computer	1	2	3	0	2	2
Software	3	0	3	2	3	5
Mechanical	4	5	9	10	13	23
Physics	3	2	5	0	8	8
Other (exchange students)	0	0	0	2	2	4
Total	41	35	76	47	77	124

Workshops were realized over two days, during the weekend, with about 10 students at each session, such a number of participants being optimal for group discussion [28]. Students were invited to work in small groups of

three to four individuals. Each workshop was about three and a half hours long and structured according to the following: presentation of the activity (15 min), activity (2h00), break (15 min), return of experience and group interviews (1h00). The same survey used to assess the empowerment of engineering education was distributed at the beginning of the first workshop and another at the end of the last one. Altogether, 34 voluntary final-year chemical engineering students attended these sessions. The specific methodology for each workshop is presented hereafter.

Complexity. For this workshop, complex case-study was selected for it has been proven to efficiently promote non-linear thinking [see 21]. More specifically in the engineering education field, Davis and Wilcock [12] have recommended the use of case studies, for it has been shown efficient to 1- place the student in the center of the learning activity instead of the teacher, 2- to expose students to real-world issues and 3- to increase student motivation and interest in a subject. The case was based on the complex analysis of the Fukushima disaster [see 16]. Each team of students was asked to identify elements (natural, technological, cultural, political,...) and analyse how their interactions have contributed to the emergence of the disaster. Students were asked to represent their analysis using a concept map.

Cooperation. This workshop aims at highlighting the value of multiple perspectives, should they be from lay people or other non-engineer experts. Therefore, role-play was selected to invite engineering students to defend perspectives that are not obvious and/or comfortable for them. Specifically, in science and engineering education, role plays have been found efficient for teaching responsible conduct of research, by inviting participants to behave like a character instead of imagining what is like to be such character, giving “an even closer approximation to actual experience than a case discussion” [41]. The role play’s scenario was directly inspired by the work of the anthropologist Melissa Checker on the scandal of the Hyde Park area pollution [see 6]. Students were asked to replay the announcement of the results of a study, made by the Environmental Protection Agency, on the air, water and earth pollution to the population of the area, such results being outrageous for the civilians. Roles available were the scientists responsible for the study, population representatives and a hypothetical anthropologist with a role of mediator. Indeed, Checker argued in her study that anthropologist can help build communication and cooperation capacities between “hard” scientists and local communities.

Emotion. As argued by Roeser [38], emotional and imaginative capacities of future engineers may be enhanced by including literature- and art-based courses in their curriculum. It can also be found in the management literature that such aesthetic inquiry can convey emotional

knowledge potentially leading to an engagement toward sustainability, and that emotional and aesthetic learning are part of an efficient crisis prevention education [see 22, 43]. As well, according to Cazeaux [5] cited in Ivanaj, et al. [22], “aesthetical process can lead to new cognitive possibilities and a sensibility that is critical of the divisions exercised by modern thought.” Therefore, we selected an art-based approach for this workshop. We adapted the aesthetic inquiry methodology developed by Ivanaj, et al. [22] for deep sustainability learning. After a quick introduction, students within each team were asked to conceive individually a metaphor, a representation of their answer to the question: “what can we do, as engineers, to prevent industrial crises?” Different tools and supplies were available, such as science magazines for images, pastels, colored markers, scissors, glue, etc. In order to trigger an emotional sensitivity, a slideshow with random pictures of technological disasters as well as successes was running in the background. Creations presentation and group discussions followed the realization of the metaphor.

4. RESULTS AND DISCUSSION

4.1 Empowerment effect of engineering education

Figure 1 presents the 10 items composing the self-efficacy scale for ethical risk management for the first- and last-year students. This scale shows a Cronbach’s alpha of 0.87, which indicates an excellent internal consistency and which is consistent with the one reported by May and collaborators [29] in their study.

This scale suggests that globally, engineering education induces no significant change in the self-efficacy for ethical risk management. Globally, like their first-year colleagues, last-year students are moderately confident in their capacity to engage in such practice, except for item 3 “Recognize the interdependency of technical and non-technical dimensions in industrial risk management”. The increase of self-efficacy for this item echoes an opening to non-technical dimensions, which, in our point of view, is positive but unfortunately not followed by a similar increase of their confidence in their capacity to operationalize such an openness (see items 6 and 8 for example). Moreover, their moderate confidence in their capacity to analyse a system to assess risks (item 1) is maybe even more problematic, even without talking about ethics, and rise serious questions about the place of risk management in their curriculum.

Figure 1. Self-efficacy scale for ethical risk management for the first- and last-year students (N= 200, alpha = 0.87, * p<0.05)

During their training, students acquire and developed great skills, which come with great responsibilities. However, the present curriculum seems not to prepare adequately students to assume those. Of course, young engineers rarely work alone or isolated in the beginning of their career. Yet, as their self-efficacy is moderate at best, they will set up ethical goals in risk management accordingly hence making them more vulnerable to potentially less ethical practices from their peers or to organizational pressures, such as speed of decision or cost reducing.

To help in this matter, we therefore propose an active-learning method inspired by the ethics of complexity, dialogue and moral emotions.

4.2 An active learning method for ethical risk management empowerment in engineering education.

Figure 2 presents the ratings for each item of the scale efficacy scale before and after 34 voluntary chemical engineering students have participated in the workshops. For each item, the influence of the workshop is positively significant. These results illustrate that these workshops have a substantial capacity of empowerment and that they seem efficient to promote, at least in the short run, ethical approaches toward industrial risk management. Moreover, many students have highlighted the fact that the absence of quotation was positive, removing the pressure for performance they usually experience during their other courses, and that allowed them to be actually more engaged in the learning.

Table 3. Examples of rich pictures from the aesthetic workshop on emotional reflection

emotional reflections are necessary to ethical deliberation, they are still having difficulties to recognize, or at least to verbalize, the specific positive utility of moral emotions such as empathy in decision-making regarding industrial risks.

The work of Nussbaum [32] would certainly help them here. For the philosopher, emotions are as much rational than cognitions. Even more, she argued that “emotions are not only not more unreliable than intellectual calculations, but frequently are more reliable, and less deceptively seductive” (Nussbaum [31] cited in Roeser [39]). However, like intellectual calculations, emotions are not infallible. Empathy is good, but not if only oriented toward closed, loved ones. Anger seems bad for decision-making, but can actually reveal injustices. Engineers can be very enthusiastic for developing a new technology, but it should not be at the expense of public safety.

Table 4. Usefulness, relevance of pedagogical approaches, comfort and relevance of developing a course for each workshop's theme (N=34).

	Complex.		Coll.		Emo.	
	Mean	SD	Mean	SD	Mean	SD
Usefulness	4.96	(0.2)	4.89	(0.3)	4.70	(0.5)
Relevance of pedagogical approaches	4.78	(0.6)	4.67	(0.6)	4.33	(1.0)
Comfort	4.11	(1.0)	3.81	(1.1)	3.56	(1.3)
Relevance of a course in the curriculum	4.96	(0.2)	4.81	(0.5)	4.59	(0.7)

Moreover, these positive findings are reinforced by the enthusiasm of the participating students. Table 4 shows their rating, made on a 5-points Likert scale, for their perception of the usefulness of these workshops, of the relevance of the selected pedagogical approaches, their degree of comfort while performing these workshops and finally the relevance to develop a full-course of ethical risk management in their curriculum covering these concepts.

Each workshop has been rated mostly as very useful and the students have evaluated that the selected pedagogical approaches were relevant to address these concepts. They have globally experienced more discomfort in the workshops addressing emotions and collaboration. These results were expected, as students were more emotionally involved in these workshops. Furthermore, role-play and aesthetic reflection activities are not activities they are used to do. However, even if this seems to be associated with a decrease in their evaluation of usefulness and relevance of pedagogical approaches, there is no significant correlation between

those. Finally, students have expressed their need for such training in risk management being integrated and developed in their curriculum. This illustrates their feeling that the present engineering education is limited in regards of such an important responsibility. Here are some edifying testimonies of students strengthening this argument:

“It is rare that we address issues with as much nuance in our training and that we get to such a personal reflection about our future profession. I think these workshops have opened our eyes on many things and we will certainly be better engineers thanks to this particular training”;

“I find our engineering training... I am sorry but defective. We need more training like these workshops. They try by adding ethics or sociology courses and tell us that is better that we are less technical, but even so... There is still work to do... I don't say that it is defective because it is not a good school, but because there are not enough open-problems, there are not enough courses like this training which enable us to think outside the box”;

“I think that what should be integrated in our curriculum is especially workshops like those. This training really allowed us to think, to see the connection with numerous dimensions. We have ethics or sociology classes, but it is not the same. This training, it shows us the link between engineering and ethics”;

“We are told during our training that we cannot discover new principles in mathematics, that we already have a lot of tools, that now we are at the optimization and sustainable development stage. But now [after this training], I realize that there is another dimension that we don't touch or that we are not made aware of. It is the reflexivity level. We have a lot of work to do”.

Engineering education often trains students to execute, but fails to empower them in critical thinking and reflexivity. However, they are able of such reflexivity and they are calling for more to be integrated in their training.

5. LIMITATIONS AND FURTHER RESEARCH

The main limitation of this study is the difficulty of generalization, as our sample is from one particular school. It could be, however, hypothesized that similar results could be found throughout the country, as all engineering programs have to be validated by the same

accreditation board. Also, the important number of chemical engineering students (37%) having participated to the survey of this study might have biased the results, hence limiting their generalization. Indeed, they may address more or less often, or more or less intensively, some of the considerations studied here in their training than students in other specialities. Further research is required to address these issues. Also, this study was not longitudinal. Last-year students are not the same individuals that first-year students four years later.

Further research should first try to assess if the positive influence of the workshops holds in time. Other research should also focus on the influence of engineering practice, by proposing to professional engineers questionnaires and workshops. It would also be interesting to assess the influence of these workshops to actual risk management practices, by analysing the risk management process regarding a project before and after this training is given. From an educational point of view, further reflections and discussions on the utility to develop this training to a full course or to keep it in the form of workshops should also be undertaken.

5. CONCLUSION

As recently argued by Carl Mitcham, the true Grand Challenge for engineering in the 21st century is to trigger critical reflectivity on what it means to be an engineer [see 30]. We, along with numerous authors, agree that this may be possible by integrating arts, humanities and social sciences in the engineering curriculum.

Many efforts have been made in the past years to open engineering education by integrating team work, sustainable development, social responsibility, ethics, emotional intelligence or creativity in the curriculum. We suggest, however, that despite such positive efforts, engineering education fails to empower students to engage in ethical risk management. This may limit their ability to critically question traditional practices. Therefore, if they reproduce in industrial organizations ethically limited practices, they might tend to set for themselves lower ethical objectives, just because they are unaware of these limits. This might be seen as a “negative” self-efficacy, leading eventually to moral disengagement in risk management practice.

We therefore have proposed an active-learning method based on the ethics of complexity, the ethics of dialogue and the ethics of moral emotions to assist and empower engineering students to later engage in ethical risk management practices. Our results suggest that this method is efficient, at least in the short run, of doing so and offers students possibilities of reflectivity on what it means to be an engineer today, a first step in engaging into the ultimate Grand Challenge of self-knowledge.

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