HEC MONTRÉAL
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ETHICS EMPOWERMENT FOR BETTER MANAGING INDUSTRIAL RISKS : ANALYSIS AND EXPERIMENTAL INVESTIGATIONS IN ENGINEERING EDUCATION AND PRACTICE

par
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RÉSUMÉ

Cette thèse est basée sur l'identification de trois enjeux éthiques relatifs 1) à la complexité de la réalité industrielle, 2) à la légitimité des perspectives multiples et 3) à la place des réflexions émotionnelles dans la prise de décision. Rédigée par articles, elle vise à promouvoir une approche éthique de la gestion des risques en ingénierie. Une méthodologie mixte est utilisée pour répondre à deux questions générales de recherche : 1) dans quelle mesure la formation et la pratique de l'ingénierie autonomisent les ingénieurs à aborder éthiquement la gestion des risques et 2) comment le pluralisme éthique appliqué à la gestion du risque pourrait améliorer cette autonomisation? Trois articles sont présentés dans le but d'apporter des éléments de réponse à ces questions.

L'article 1 est basé sur une revue systématique de la littérature en éducation en ingénierie. Il révèle que le lien entre éthique et gestion des risques est encore sous-développé dans ce domaine. Il est alors suggéré que cette connexion soit développée dans la formation des ingénieurs afin de promouvoir des pratiques davantage responsables. Plusieurs avenues et enjeux sont identifiés et analysés afin d'appuyer la communauté de l'enseignement en ingénierie dans ce projet.

L'article 2 utilise les résultats d'un questionnaire répondu par 200 étudiants en ingénierie. Il analyse d'une part l'influence de leur formation universitaire sur les perspectives relatives aux enjeux éthiques en gestion des risques et, d'autre part, sur la capacité d'autonomisation de cette formation à aborder la gestion des risques éthiquement. Cette analyse remet en question les préjugés sur le portrait stéréotypé de l'ingénieur, mais souligne néanmoins la nécessité d'amélioration dans leur formation. En effet, analysant l'autonomisation en gestion éthique des risques au travers du concept d'auto-efficacité, il est suggéré que l'actuelle formation ne réussit pas à l'améliorer. Une méthode pluraliste d'apprentissage actif, qui a été opérationnalisée sous forme d'ateliers avec 34 étudiants de dernière année, est alors présentée. Considérant les résultats d'un questionnaire et des entrevues de groupe, cette méthode semble efficace pour motiver les étudiants à s'engager dans une approche éthique de la gestion des risques, tout du moins à court terme.

Finalement **l'article 3** utilise les résultats d'un questionnaire répondu par 178 ingénieurs professionnels. Il analyse plus spécifiquement comment a) l'expérience de la pratique de gestion du risque, b) l'ethnocentrisme professionnel ainsi que c) la conscience émotionnelle influence la perception d'efficacité en gestion éthique des risques. Ces résultats suggèrent que si l'expérience semble bien avoir une influence positive, l'ethnocentrisme professionnel semble, en revanche, avoir une influence négative. En outre, la conscience émotionnelle présente un effet médiateur complet sur cette influence. Ainsi, bien que les formations multidisciplinaires soient souvent proposées comme moyens pour limiter les biais relatifs à l'ethnocentrisme, il est suggéré dans cet article que de telles formations devraient également intégrer activement les réflexions émotionnelles, leur développement pouvant certainement aider les ingénieurs à dépasser leur perspective technique du risque. Plus sensibles aux dimensions complexes et éthiques de la sécurité, les ingénieurs seraient plus enclins à s'engager dans une approche délibérative et multidisciplinaire de la gestion des risques.

Cette thèse, par la contribution empirique et conjointe de trois articles, présente de nouvelles perspectives et connaissances sur le rôle favorable que l'éthique, et particulièrement le pluralisme éthique, peut jouer dans le développement de pratiques d'ingénierie plus sécuritaires et responsables.

Mots clés : Complexité, perspectives multiples, émotions, pluralisme éthique, gestion du risque, formation d'ingénieur, pratique d'ingénierie, autonomisation, auto-efficacité;

Méthodes de recherche : Revue systématique de la littérature, questionnaires, ateliers d'apprentissage actif, entrevues de groupe.

ABSTRACT

Identifying three important ethical issues relative to 1) the complexity of industrial reality, 2) the plurality of legitimate perspectives and 3) emotional reflections in decision-making, this thesis-by-article aims at promoting an ethical approach of risk management in engineering. Using a mixed methodology, two main research questions are addressed: 1) to what extent current engineering education and practice empower engineers into an ethical approach of risk management, and 2) how ethical pluralism applied to risk management could enhance this empowerment? Three articles are presented in this thesis to try and answer these questions.

Article 1, using a systematic literature review in engineering education, reveals that this nexus between ethics and risk management is still underdeveloped in the literature. It is then argued that the link between risk management and ethics should be further developed in engineering education in order to promote the progressive change toward more responsible engineering practices. Several research trends and issues are also identified and discussed in order to support the engineering education community in this project.

Article 2, using the results of a survey answered by 200 engineering students, analyses a) the influence of the current academic engineering education on perspectives regarding ethical aspects of risk management and b) its capacity of empowerment into an ethical approach of risk management. This analysis challenges the existing literature and illustrates the necessity to change the stereotypical portrait of the engineer. However, it also highlights the need to improve engineering education. Indeed, assessing empowerment through the concept of self-efficacy, it is suggested that the present engineering education fails to improve ethical risk management efficacy. Therefore, a pluralistic active-learning method, carried out in the form of workshops with 34 last-year students, is proposed to help in this matter. Using questionnaires and group interviews, it is suggested that such an approach is efficient, at least in the short run, to motivate students to engage in ethical risk management.

Finally, **article 3**, using the results of a survey answered by 178 professional engineers, specifically analyzes how a) experience of the practice of risk management, b) professional ethnocentrism and c) emotional awareness influence ethical risk management efficacy. The results suggest that even though risk management experience has a positive influence, professional ethnocentrism is significantly and negatively related to ethical risk management self-efficacy. Furthermore, emotional awareness presents a fully mediating effect on this relation. Therefore, while multidisciplinary education is often suggested as a way to limit professional ethnocentrism biases, it is argued in this article that such an approach should extend its rationality by actively involving emotional reflections, as their development could support engineers transcending their technical perspective on risk. Being more sensitive to complex and ethical dimensions of safety, engineers would be more prone to engage in an interdisciplinary and deliberative approach of risk management.

This thesis, by the combined contribution based on empirical evidences of these three articles, offers new practical insights on how ethics, and specifically ethical pluralism, through an appropriate educational approach and frame of analysis, may favourably contribute to potentially more responsible and safer engineering practices.

Keywords : Complexity, plurality of legitimate perspectives, emotions, ethical pluralism, risk management, engineering education, engineering practice, empowerment, self-efficacy;

Research methods : Systematic literature review, surveys, active-learning workshops, group interviews.

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LIST OF ABBREVIATIONS

Abbreviations	Meaning
ABET	Accreditation Board for Engineering and Technology
CEAB	Canadian Engineering Accreditation Board
CSR	Corporate Social Responsibility
EO	Emotional Openness
ERME	Ethical Risk Management Efficacy
ETA	Event Tree Analysis
FMEA	Failure Mode and Effects Analysis
FTA	Fault Tree Analysis
HAZID	Hazard Identification
HAZOP	Hazard and Operability study
HRO	High Reliability Organization
HRT	High Reliability Theory
I2SI	Integrated Inherent Safety Index
ISI	Inherent Safety Index
LOPA	Layer of Protection Analysis
NAE	National Academy of Engineering
NAT	Normal Accident Theory
O&G	Oil and Gas
OFOR	Organizational Frame of Reference
OIQ	Ordre des Ingénieurs du Québec
PE	Professional Ethnocentrism
PIIS	Prototype Index for Inherent Safety
PRA	Probabilistic Risk Assessment
QRA	Quantitative Risk Assessment
SE	Self Efficacy
SHE	Safety, Health, and Environment
SRA	Simplified Risk assessment
S-WIF	What-if and Structured What-if

À ma mère, Annie,

Qui a tant donné;

À mon père, Georges,

qui a su l'être d'une merveilleuse façon.

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Faire un doctorat est un grand privilège. Le privilège de penser librement, autrement, de pouvoir être critique, de chercher à comprendre et de s'enrichir de cette connaissance. C'est aussi le privilège d'avoir l'occasion de transmettre cette connaissance, d'être remis en question et d'apprendre, encore, de ces échanges. Mais faire un doctorat c'est aussi une épreuve, une traversée en solitaire où les tempêtes succèdent aux temps calmes, les doutes aux certitudes, et les angoisses, aux joies. M'engager et persévérer jusqu'au bout de ce voyage n'aurait pas été possible sans le soutien de nombreuses personnes, que j'aimerai ici remercier.

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FOREWORDS

« L'œuvre du peintre, de l'écrivain, de l'architecte, toutes se révèlent identiques à celles de l'ingénieur, du chimiste, de l'organisateur. Non pas une fantaisie arbitraire, ni un acte de pure volonté, mais la découverte des formes qui harmonisent les besoins et les aspirations de l'Homme intérieur avec les lois qui régissent l'environnement naturel. Formes qui sont ses artéfacts au sein du monde dans lequel il vit. »

Herbert A. Simon, The Sciences of the Artificial,
forewords in the French first edition (1974), p. 376 in the 2004 edition

« […] complexity is invisible in the disciplinary division of the real. In fact, the first meaning of the word comes from the Latin complexus*, which means what is woven together. The peculiarity, not of the discipline in itself, but of the discipline as it is conceived, non-communicating with the other disciplines, closed to itself, naturally disintegrates complexity »*

Edgar Morin, Restricted complexity, general complexity, 2007, p.6

I am an engineer, even though after five years working on this thesis my conception of what engineering is greatly evolved. I have graduated from an engineering school in 2010 and engaged in a master of applied science right after. In 2010 and 2011, two major catastrophic events occurred: the Deepwater Horizon blow-up and the Fukushima disaster. Of course during my training I had heard words about other industrial catastrophes, such as Bhopal or Challenger, but to actually witness these two events would definitely change my perspectives on engineering. They make me wonder what we do wrong when designing these technologies, so that we could not prevent such disasters.

Our responsibility was obvious for me, as ultimately we had created these processes inseparably from their catastrophic potential. At first, an easy explanation appeared: these events were isolated cases and happened because their design was flawed. Unfortunately a quick look at historical databases shows that they were far from unique, and the future would also show that they were not the last either. It was also reasonable for me to believe that the engineers who had designed these plants were not that incompetent. The explanation therefore, had to be more *complex*. It was not their design that was flawed, it was the approach itself used for their design. Essentials dimensions had to be missing.

I needed answers to my question. I have therefore decided to engage into what was for me uncharted territories, without being warned that there would be dragons. This thesis tells my journey, and hopefully, it is just the beginning.

Thesis overview

This thesis-by-article is organized into six main parts, excluding the conclusion. First, the concepts of crisis and risk management are defined in the introduction, where the need for ethics in these activities is also presented.

Next, as they were my first major encounters, foundational theories of crisis management are succinctly presented in the first part of the first chapter. They represent the context of this thesis, and bring elements to challenge the engineering approach of risk management. These theories are deeply rooted in a systemic and complex perspective, and give to ethics a central role for it helps targeting the deepest and most latent elements that could lead to a crisis. These two aspects are developed in the second part of the first chapter. Finally, the general approach of risk management typically used in engineering is discussed along with several issues. Ethical pluralism is then presented as a frame to address these issues, before concluding with the presentation of key elements of this research and methodological notes.

The second, third and fourth chapters present the articles of this thesis. The first article is co-authored with Thierry C. Pauchant, Ph.D. and Philippe A. Tanguy, Ph.D.. This article has been published in *Science and Engineering Ethics* (DOI: 10.1007/s11948-016-9777-y). The second article is also co-authored with Thierry C. Pauchant, Ph.D. and Philippe A. Tanguy, Ph.D.. It has been submitted to *Engineering Studies* and proposed for a communication at the Canadian Engineering Education Association's Annual Conference. At the time of writing these forewords, its acceptance for the publication is not yet determined. However, the article has been accepted for the conference and selected for a special symposium: Innovation and Engineering Leadership. Finally, the third article is co-authored with Kevin J. Johnson, Ph.D., Joé T. Martineau, Ph.D. and Thierry C. Pauchant, Ph.D. It has been submitted to *Safety Science*, but its acceptance is not yet determined. However, it has been accepted for the annual conference of the Association Francophone pour le Savoir (ACFAS).

Finally, the general conclusion presents an overview of this thesis as whole while addressing more general remarks, before discussing the theoretical and practical contributions, as well as the limitations and avenues for further research.

INTRODUCTION

Crisis: portrait of an elusive process

Charles Darwin, in his work "On the Origin of Species", enlightens the fundamental goals of animal species: the survival of the individual, on one hand, and the survival of the species, on the other. For mankind, achieving this goal meant mastering his environment. Thanks to the tremendous and simultaneous development of its brain, hand and language, the human acquired a safety and autonomy level like no other specie has been able to. Science and technology allowed him to handle his environment to a point that we have entered a new era, the Anthropocene, wherein the Earth system is now driven by human technological activities (Steffen, Broadgate, *et al.*, 2015).

Since the industrial revolution, the modernization of our society has been possible thanks to the development of complex technologies. Paradoxically, these technologies have also become a source of potential threats inherently different from those related to the traditional tools development by their magnitude as well as their spatial and temporal nature (Lagadec, 1981). The last decades have engraved in the collective memory numerous technological and industrial crises: Three Mile Island (1979), Bhopal (1984), Chernobyl (1986), Challenger (1986), Piper Alpha (1988), Exxon Valdez (1989) or more recently AZF (2001), Columbia (2003), Deepwater Horizon (2010), Fukushima (2011), Lac Mégantic (2013) or the Bento Rodrigues dam (2015). The exhaustive list of technological crises is by all practical means infinite (Mitroff *et al.*, 1988) and is not the object of this thesis. However, a review of the major industrial disaster[1] during the last

[1] To be recorded in the EM-DAT Database as major technological disaster, an event has to fulfil at least one of the following criteria: ten or more death, hundred or more affected, declaration of state of emergency, call for international assistance (Guha-Sapir *et al.*, 2015). The following type of event composes the technological disaster group: industrial accident (gas leak, chemical spill, explosion, etc.), transport accident (air, water, rail and road) and miscellaneous accident (fire, collapse, explosion).

century clearly shows the problematic evolution of the phenomena, as illustrated by Figure 1.

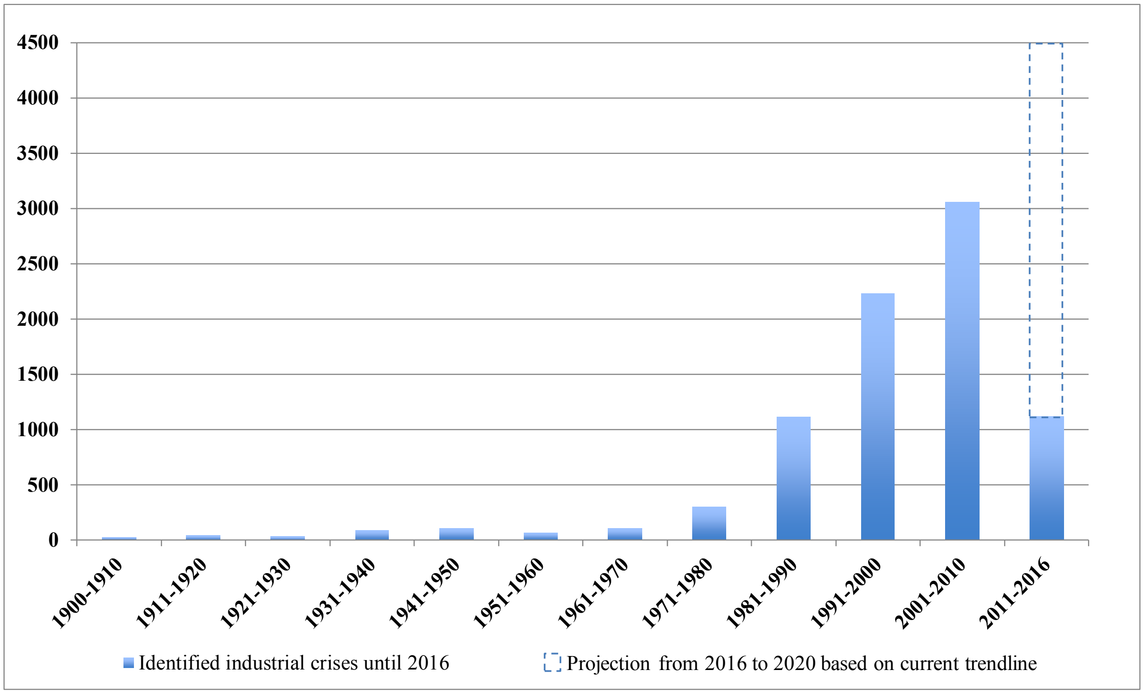

Figure 1. Evolution of the number of technological crisis from 1900 to 2016 and projections to 2020 (EM-DAT Database, Guha-Sapir, Below et al., 2015 updated in 2016)

But what is understood as a crisis? A classic definition, from a management point of view, would be that a crisis is an organizational event characterized by a low probability of occurring, with serious consequences to the organizational stakeholders and the natural environment, and which threatens the existence of the organization (P. Shrivastava, 1987a; P. Shrivastava *et al.*, 1988). Presently, the most widely used definition is given by Pearson and Clair (1998, p. 60) (Crandall *et al.*, 2013), for whom a crisis is a "low-probability, high-impact event that threatens the viability of the organization and is characterized by ambiguity of cause, effect, and means of resolution, as well as by a belief that decisions must be made swiftly". Such probabilistic-based definition promotes a calculus approach which may be considered limited for it usually hardly takes into account the social, political, symbolic and moral aspect of a crisis and rejects the complexity of the present reality (Lagadec, 1981; Leveson, 2011; Pauchant & Mitroff, 1995; Topper & Lagadec, 2013).

A more open definition is proposed by Lagadec (1996). For the author, a crisis is a unique and major event with potentially disastrous outcome, which calls for an immediate reaction, but which is not limited in space, time, stakeholders or procedures and which finally ask for a complete restructuration of the concerned system. As well, Pearson and Clair (1998, p. 60) proposed the following precision to their aforementioned definition to include some of these aspects: "Ambiguity of cause, effect, and means of resolution of the organizational crisis will lead to disillusionment or loss of psychic and shared meaning, as well as to the shattering of commonly held beliefs and values and individuals' basic assumptions". Finally, some authors have given a more social perspective to the crisis, defining it as a "a state in which the social fabric is disrupted and becomes dysfunctional to a greater or lesser extent" (Fritz, 1961, cited in Alexander, 2005, p. 27). Two main characteristics stand out from these definitions: the global disruption of the concerned system as well as a complete questioning of the basic assumptions supporting the very existence of the system, thus transcending the mere technical aspect usually recognized (Pauchant & Mitroff, 1990). Except these two characteristics, it appears clearly that there is no complete and consensual definition of what is a crisis (Roux-Dufort & Lalonde, 2013). Indeed, for Topper and Lagadec (2013), the complexity of what is a crisis, as it is precisely characterized by this collapsing of references and meaning, cannot be handled in a single definition :

> To insist, therefore, on agreement as a precondition for studying ill-structured problems, is to ignore and to deny their basic nature. It is to misinterpret them ontologically. When crisis management experts call for agreement on the definition of basic terms, in effect, they are committing the same kind of error that we accuse practitioners of making when they ignore the complexity of crises. […] "Crisis" will resist any attempt to be "defined". (Topper & Lagadec, 2013, p. 8)

Finally, one may ask if characterizing the nature of a crisis following its origin – natural, technological, financial, etc. – would not be pertinent. Such an attempt would, however, also be a rejection of the complexity of a crisis, as these dimensions are more and more intermixed, especially in our globalized world (Alexander, 2005; Denis, 1993) and with the present level of impact of anthropogenic activities on the Earth system (Steffen, Richardson*, et al.*, 2015).

Crisis and risk management

Yet, this uncertainty on the nature of a crisis does not mean that it is not possible to take action in prevention of a crisis. And here is a key word: prevention. As numerous authors denounce, crisis management is more than often mingled as emergency management, or crash management (Crandall *et al.*, 2013; Denis, 2002; Pauchant & Mitroff, 1995; Pearson *et al.*, 2007). This misconception is based on the confusion of what a crisis is, often limited to the disastrous punctual event, which is actually just the tip of the iceberg. Crisis management is not the management of a unique catastrophic event but of a latent, merely visible, process (Roux-Dufort, 2007; P. Shrivastava *et al.*, 2013). Crisis management is a circular, everlasting process, learning from past crises to better reveal and manage the incubation phase of a new one, as the crisis itself is a long-term process, often starting decades before the trigger event allows it to be visible, and with more or less long-term consequences as well (Crandall *et al.*, 2013; Denis, 2002; Mitroff *et al.*, 1987; Pauchant & Mitroff, 1995; D. Smith, 1990). Numerous theories have been developed to improve crisis management, enlightening different dimensions of the crisis and offering different means of action. These main theories will be presented succinctly in the first part of the first chapter.

Crisis management, unlike common thinking, is therefore highly related to risk management. However, as explain by Laufer (2007, pp. 26-27), it is important to make the distinction between the risks that managers or engineers accept to face on an everyday basis, those that almost define their role of decision makers, and the risk that they refuse to see, those that "exceed the realm of their customary sphere of action" which is precisely the object of this study. Risk management, as considered here, do not refer to the "organized, optimistic and recurring" part of business activities, but to those, specifically, that in the unfortunate event of their realization, will challenge all meaning given to these activities. In order to focus on this preventive aspect of crisis management, the terms *risk management* will therefore be used in this thesis.

On the need of ethics in risk management

Ethics is defined as a process of critical reflections based on a desire for good practices (Pauchant, 2007, based on Ricoeur, 1990). It is one of the determinants of the organizational practice of risk management (Lassagne, 2004), and an effective risk management process is in itself an ethical activity (Crandall *et al.*, 2013; Guntzburger & Pauchant, 2014; Pauchant *et al.*, 2008; Pauchant & Mitroff, 1992a, 1995) as it can be seen as a long-term process of critical reflections for better corporate practices or processes. Therefore, as it will be developed in the second part of the first chapter, ethics is a fundamental part of risk management. In the most recent politico-financial crises, such as Enron (2001), Worldcom (2002), Xerox (2002), Permalat (2003), the Société Générale (2008), Lehman Brothers (2008), Libor (2011), or the recent HSBC Swiss Leaks (2015), it is relatively easy to acknowledge the ethical dimension, or maybe more accurately, the lack thereof.

By contrast, this is more difficult in the case of technological or natural catastrophes, often imputed to technical failures, unsafe human action or natural forces. However, a systemic analysis of past disasters, such as Bhopal (P. Shrivastava, 1987a), Challenger (Vaughan, 1997), the Nestucca oil spill (Deschamps *et al.*, 1997), Katrina (Jurkiewicz, 2009) or Fukushima (Guntzburger & Pauchant, 2014), clearly highlights the influence of the lack of ethics in the appearance of those crises: profit over safety mindset (Bhopal, Nestucca and Fukushima), corruption (Bhopal, Katrina and Fukushima), a lack of empathy (Bhopal and Katrina), a rejection of whistleblowers and weak signals (Challenger and Fukushima), and a pathological organizational culture (Bhopal, Challenger and Fukushima) are just few examples.

As presented before, a classic risk management, in particular in the field of engineering, follows mainly a probabilistic and sequential approach to the events, which is not adequate in front of the complexity of our current systems (Leveson, 2004; Leveson *et al.*, 2009; Murphy & Conner, 2012; Ramana, 2011; Topper & Lagadec, 2013). Such rational and reductionist approach generates a questionable mathematical morality (Beck, 1992), and an ethical systemic risk management allows precisely exceeding this limit by deepening the reasoning on the potential consequences of the organizational activities (Pauchant *et al.*, 2008; Pauchant & Mitroff, 1995).

In order to present the context in which this study takes place, the foundational theories in crisis management will be presented in the first section of the first chapter. In the second section, it will be analyzed how these theories of crisis management, grounded in a systemic perspective of the organization, try to grasp the complexity of the phenomena they wish to explain and that ethics helps in this process by targeting the deepest and most latent elements that could lead to a crisis.

Finally, as the start point of this thesis are the technical approaches mainly used in the engineering field, they will be presented and their limits analyzed in the last part of the first chapter. Specifically, it will be shown that within the engineering field, traditional methods of classic risk management fail to match the complexity and diversity of organizational activities, yet recognized by the founder theories of crisis management. Using the concept of fragmentation, it will be hypothesized that the engineering formation influence this narrow approach. Therefore, it will be suggested that an ethical diversity based on complexity, deliberation and emotion could help empower engineers to engage in an *ethical risk management*.

Following the research questions proposed in conclusion of the first chapter, the second chapter (article 1) will present and analyze a systemic review of the nexus between ethics and risk management in the engineering *education* literature. Then, in the third chapter (article 2), the influence of engineering *education* on biases regarding risk management will be analyzed. Unexpectedly, it will be shown that this influence is non-significant. However, engineering education does not seem to empower adequately engineers to engage in ethical risk management. Therefore, an active learning method will be presented and its efficiently to do so will be analyzed. The fourth chapter (article 3) will then present the influence of engineering *practice* on this empowerment and the role of emotion in this relation. Finally, a general discussion on the results of this thesis and their limitations, as well as on the further research avenues will be presented in the final chapter.

A Complex and Ethical Approach of Risk Management

Crisis management represents a real challenge for managers, engineers or policy makers as it goes beyond their day-to-day activities and transcends their action frame of reference (Boin, 2009; Murphy & Conner, 2012; Pearson *et al.*, 2007). Crises are usually considered as low-probability unique events. Therefore, they are often managed as exceptions. But, when a systemic perspective is adopted and crisis considered as an ongoing, non-linear process starting long before the trigger event, a questioning of what crisis management is and how it should be integrated in day-to-day organizational activities emerges (Roux-Dufort, 2007).

Foundational theories in crisis management

As a response of the increasing number of organizational crises, numerous theories have emerged to face social and technological problems related to organizational activities during the late 70's and 80's (Topper & Lagadec, 2013). During this period, different schools of thought in the US and Europe regarding what a crisis is and how it should be managed appeared (Pidgeon, 2010). They will now be presented chronologically.

Manmade disaster - Turner (1976)

The basic assumption supporting the model of the British sociologist Barry Turner is that the source of a crisis is not purely technical, but human and organizational as well (Turner, 1976). For the author, the organization is a cultural system with specific objectives and resources. The actors in the organization have rites and routines they used to cope with uncertainties related to these objectives. For Turner (1976), as the organization is an open system, actors have a limited comprehension of the consequences of their actions.

To reduce and deal with the complexity of the situation, organizational actors use numerous simplifying assumptions, triggered by a bounded rationality (Simon, 1955). Therefore, the greatest challenge is to choose what should be ignored and to what extent, the organization being thus defined or bounded by what has been discarded (Weick, 1998). Using the concept of organizational intelligence, or information, of Wilensky

(1967), Turner (1976) argues that it is the lack of perception, judgment and foresight that is the source of organizational crisis. These lacks may be the consequences of the rigidity of institutional believes, disturbances or lures from the environment, the lack of internal and external attentiveness, risk minimization as well as organizational culture (Pidgeon, 1998).

One last important point of the theory of Turner (1976) is the concept of latency. Indeed, for the author, an organizational crisis is only the results of years of incubation during which the aforementioned lacks have undermined the organization. Paradoxically, it is precisely because of the organized structure of an organization that each individual and collective error can emerge and spread. This is what Weick (1998) calls the organizational paradox.

The risk civilization - Lagadec (1981)

For the French political scientist Patrick Lagadec, contemporary technological risks are inherently different from those related to the traditional tools development, by their magnitude and their spatial and temporal nature (Lagadec, 1981, 1987). The author used the Chernobyl disaster to illustrate this theory. Indeed, the nuclear blast has had immediate consequences, but also long-term consequences, such as cancer and genetic mutations. Moreover, if people killed by the blast were necessarily close to the central, many people sick from cancer were remotely located, as far as thousands of kilometres.

However, the essence of this theory is not just to say that present crises are just "bigger" than yesterday, it is to reveal the complexity of those crises by including the political, communicational, economic, social as well as environmental issues (Lagadec, 1987). It is then a new perspective that Lagadec (1981) offers about what risks and crises are. Base on this point of view, the author proposes recommendations to enhance crisis management. Asking to go beyond mere legislative regulation and technical safety measures, he proposes to embrace and face the uncertainties relative to the organizational activities, which means not to oversimplify the situation, not to withdraw onto oneself and to develop external relations and finally to increase the preparation of all the organizational actors, from day-to-day partners to emergency teams. Finally, and above all, he asks for more introspection and to question each mindset, from the leading managers to the floor employees, the politics, the Medias as well as the general population, as it is, for the authors, the main source of error[2] (Lagadec, 1981).

Normal Accident Theory (NAT) - Perrow (1984)

The theory developed by the American sociologist Charles Perrow (1984) is one of the most important model in the field of crisis management (S. Shrivastava *et al.*, 2009; Weick, 2004). Using the complexity theory, Perrow (1984) argues that two dimensions are directly connected to the generation of a crisis, called "system accident": the interactive complexity of the system and the coupling of its parts. Therefore, more a system is complex, and more the parts of this system are tightly coupled, more it will be able to inherently generate a crisis. This is the reason he named his theory "Normal Accident", referring not to the frequency of occurring, but to the deep crisiologic nature of the system (Perrow, 1984, p. 5).

The complexity and the coupling of the system are thus essential dimensions for two reasons. On the first hand, more a system is complex, with linear and non-linear interactions, more it will be difficult to understand it, whether during the conception or exploitation period. On the other hand, more the parts of the system are tightly coupled, more likely involuntary[3] errors or failures may spread quickly, with unpredictable consequences caused by the non-linear interactions within the system. For the author, systems too much complex and tightly coupled should simply be discarded despite the regulatory, managerial and technical effort to increase safety, the nuclear industry being the prime example (Perrow, 2011).

Thus, the NAT theory is deeply pessimist, because of the inherent unsafe nature of complex systems (Leveson *et al.*, 2009), as any attempt to reduce the coupling will

[2] This argument is well illustrated in the famous analysis of the Bhopal disaster by P. Shrivastava (1987a) or the recent analysis of the Fukushima nuclear disaster by Guntzburger and Pauchant (2014).

[3] Originally, the NAT model has not been developed to consider voluntary and designed errors. However, this has been done recently by Perrow (2007) by integrating the concept of executive malfeasance. The author also denounces the issues relative to the concentration of the economic, politic and energetic power.

increase the complexity and reversely. Therefore, such systems should be discarded, drastically reduced or deeply reconfigure (Perrow, 1999, p. 369).

Risk society - Beck (1986)

The concept of Risk Society[4] developed by the German sociologist Ulrich Beck (1992)[5] is based on an observation close to Lagadec's: the inherent risk of our developing society is decidedly different than before. The author uses explicitly an ethical approach to develop his theory, especially with his critical reflection on risk acceptation. Indeed, the notion of risk, and more specifically acceptable risk, is based on an organizational and political rational – or wanting to be – decision process. The risk is then socially accepted thank to a scientific discourse based on a calculus approach which legitimates it (Tollefson, 2014).

For Beck (1992), the risk calculus is a technological moralization leading to a mathematical ethics destitute of morality. The risk calculus allows a sort of social pact, with safety assured and uncertainties removed thanks to a regulation system which may eventually suffer a legitimation crisis in the event of a disaster (Habermas, 1975), as it has been the case, at least momentarily, with the nuclear industry and the governments which support it after the Fukushima disaster.

Until now, this social pact allowed the evolution of society but it is now trampled by the nuclear, chemical or genetic industry[6], as their effects may be potentially disastrous for a large geographic scale and time span. Indeed, the worst-case risk scenario considered yesterday and for which organizations and insurance companies were prepared, is not possible today, for such technologies. Statistics and related insurances are not relevant in case of global damages in space and time, which is precisely the present worst-case scenario. For Beck (1992), this leads to an organizational and political denial, reinforce

[4] Numerous later contributions have enabled the development of a theory of risk. For example: Giddens (1990), Luhmann and Barrett (1993) or (Douglas, 1994).
[5] His work has first been published in 1986 in German.
[6] And even standard organizational activities can now be considered with the global warming issue (Steffen, Richardson, *et al.*, 2015).

by the foolproof technological dogma, science and expert, which the author calls an "organized irresponsibility" (Elliott, 2002).

In front of this issue, engineers are directly concerned. Indeed, the author highlights the paradox between the limit of their calculus of risk and their responsibility to assure that a technology is safe or not. The amalgam between absolute and relative safety, which allows engineers to save face in a case of disaster, is also denounced. In order to improve this risk society, Beck (1992) proposes the technological development to be deeply multidisciplinary, based on a division of the decisional power, as well as on a complete transparency regarding technological risk in order to freed public and politics from technocracy.

Finally, Beck (1992) grants a particular place to the environment and its protection, highlighting the close long term relation between economy and ecology. He proposes the social project of Ecological Enlightenment, as a daily source of individual and institutional reflection, in order to lead to an ecological democracy. Such project asks for new relations between science and business, science and politics, science and society, but also for the development of a public science, guardian of social issues and constructive opposition to the technological development. This deeply blurs the boundaries between ethics and crisis management as it will be detailed in the next section of this chapter.

High Reliability Organizations (HRT) - Laporte/Weick (1987)

The project led by the Berkeley group of science politics in the late 80's is the second best-known school thought with the NAT theory of Perrow, precisely because of the long debate over these two theories (S. Shrivastava *et al.*, 2009). Indeed, the High Reliability Organizations Theory (HRT), developed by Todd R. La Porte, Gene Rochlin, Karlene Roberts, Karl Weick, and Paula Consolini, is based on the observation that some complex and tightly coupled organizations, such as air traffic control, have very few failures (Bourrier, 2011).

This observation is explained by a strong organizational culture, specific to high reliability organizations, and developed around three points (La Porte, 1996; Pidgeon, 1998): 1- safety is the prime objective of the organization, instead of profit, 2- a set of measures allowing for a perpetual enhancing of the safety of the organization, such as flexible structure, redundancy, dynamic and decentralized authority and objective negotiation and 3- a set of values such as a deep commitment to problem solving, responsibility and the acknowledgment of expertise. Thus, the fundamental difference, between NAT and HRT, lies in the possibility of safety improvement in complex systems.

For Perrow (1999, p. 369):

> The fundamental difference between NAT and HRT is that HRT believes that if only we try harder we will have virtually accident-free systems even if they are complexly interactive and tightly coupled, while NAT believes that no matter how hard we try we will still have accidents because of intrinsic characteristics of complex/coupled systems.

Several studies tried to close the debate. Some authors argue that the organizations studied by the Berkeley group were not really complex or tightly coupled and that the debate is therefore irrelevant (see, for example Leveson *et al.*, 2009). La Porte himself answers Perrow's criticism arguing that the fundamental difference between the two approaches does not allow any comparison (La Porte & Rochlin, 1994). Other authors tried with more or less success to reconcile the theories (e.g. S. Shrivastava *et al.*, 2009). Above all, it seems that the main difference between HRT and NAT is relative to the elusive nature of the concept of crisis, its multivocal definition as well as what is chosen as a proxy to determine if there is or not a crisis.

Anatomy of a crisis - Shrivastava (1987)

One of the main contributions of Paul Shrivastava in the earliest developments of the crisis management field is his deep and complex analysis of the Bhopal chemical disaster triggered by the explosion of the Union Carbide fertilizer production plant located in Bhopal, India, December 3rd, 1984. Capitalizing on the theories of Turner and Perrow, he gives a concrete illustration of the complexity of a crisis, which results from the complex interactions of human, organizational and technological factors, such interactions being embedded in a cultural, social, economic and political context (P. Shrivastava, 1987a, 1987b; 1988). Therefore, the more a high risk technology is based on weak organizational and social infrastructures, the greater is the potential for a crisis to occur. For P. Shrivastava (1987a) the distinction between accident and crisis is therefore based on this definition, the later being the results of the incapability of the social system to cope with the former.

Based on the same observation as Turner for which organizational actors use numerous simplifying assumptions, he developed the concept of Organizational Frame Of Reference (OFOR) which "delineate domains of inquiry that organizations regard as appropriate" (P. Shrivastava *et al.*, 1987, p. 97). If this OFOR is useful for every day organizational decision-making, it may be the source of failures, triggering irrationality in organization and, potentially, crises. The author also stressed the necessity to consider the interactions of emotional factors with this OFOR. Moreover, lying somewhere in between the NAT and HRO theories, Shrivastava (1987a) argue that crises are evitable if concerned stakeholders efficiently cooperate.

Finally, there is a pluralist ethical dimension in the work of Paul Shrivastava on crisis management going beyond a classic utilitarian cost-benefice analysis. Indeed, such a point of view is inappropriate for the individuals who may profit from the organizational activities are usually not those which may suffer from them - especially when considering multinational companies such as Union Carbide in developing countries - (Marcus, 1988). Ecological environment and sustainability clearly also permeate his reflection on crisis management, which he will later developed in his work on ecocentric management for example (see P. Shrivastava, 1995).

Human error - Reason (1990)

Three hypotheses are at the base of the accident theory developed by British psychologist James Reason and : 1- crises emerge in socio-technical complex systems which have nevertheless safety regulation, 2- a crisis is not the result of a unique event but the consequence of the interaction of many elements, each independently necessary but not sufficient for the crisis to emerge and 3- human failures lies at the heart of crises, not technical failures (Reason, 1990).

Therefore, just like Turner, it is the human failure which is analyzed. Two categories are distinguished: the active and the passive, or latent, failure. The former is associated to the trigger event of a crisis, such as errors of manipulation, regulation violation, etc., and is placed at the operator level. The later regroups all the decisions taken by the top management, which potentially weaken, in the long term, the whole organizational safety system. For the author, it is impossible to predict all the potential active failures whereas it is much easier to spot passive ones. Hence, a commitment to prevent active failures is necessary, but not sufficient.

Based on a medical metaphor - one of the most inspiring sources in the field of crisis management (Roux-Dufort & Lalonde, 2013) - the author characterizes passive failures as pathogenic elements, which weaken the organizational immune system. Thus, the more the pathogenic elements are in the system, the more the chances for passive and active failures to interact and a crisis to emerge. Moreover, this process may be reinforced by the potential blindness or ignorance of these failures and imperfections by the managers (Roux-Dufort, 2009).

This process of failure interaction echoes directly the interactive complexity of a system, as defined by Perrow (1984). Also, more an individual is in the top of the organization, more he will have the capability to generate pathogenic elements. Reason (1990) identifies five basic elements of any production system which their relative failures: 1- the top management and their decisions (decisional failures, passive), 2- strategic department(s) which implement and supervise these decisions in the relative sector of the organizations (management failures, passive), 3- material and human resources (precondition for unsafe action, passive), 4- the spatial and temporal sphere of action of the organizational activities (unsafe action, active) and finally 5- failure of safety systems (safety failure, passive and active).

These failures create holes or windows for an accident opportunity to spread and lead to the emergence of a crisis. This image of holes in safety layers through which failures will spread is the reason why this model, developed in cooperation with the nuclear engineer John Wreathall, is called the “Swiss Cheese” model. However, this representation has led to the perception that this model was static and linear, therefore limited regarding complex systems. This is actually a misinterpretation, as it is the unforeseen concomitance of dynamic failures that are at the base of the work of Reason and Wreathall (Larouzee & Guarnieri, 2014).

For Reason (1990), the primary source of systemic failures lies in the top management, then spread in the lower level. These failures are inherent to the organizational system, are strongly influenced by the organizational culture and are the counterpart of the production (Reason, 1990, 1998). Indeed, within an organization, limited resources are allocated either for production or safety. In the short term, managers often perceive these two goals as distinct and incompatible, and usually promote production. Moreover, this decision may be influenced by numerous psychological barriers and organizational pressure.

Hence, the author proposes a retroactive informational system centred on safety, spreading back from each layer to the decisional sphere and based on several indicators relative to each layer. Finally, using the classification of Westrum (1988), Reason (1990) identifies three different kind of organization, based on the reaction of the top management once this knowledge is acquired: 1- the pathological organizations, with no safety system and which promotes widely production over safety, 2- the calculating organization, with classic safety measures but without global vision and finally 3- the generative organizations, the best example being for the author the HROs identified by La Porte and the Berkeley group.

Grounding crisis and risk management in complexity

These theories about crisis and crisis management, mainly developed by sociologists and succinctly summarized above, are mostly interpretative and descriptive, offering numerous insights about the nature of organizational crises and their root causes, but not prescriptive enough to implement managerial practices. More or less at the same period, several authors such as Ian Mitroff, Thierry Pauchant, Paul Shrivastava, Danny Miller and Denis Smith have adopted a more managerial approach to propose models and practices, based on these theories, to better understand what are crises and improve their management (see, for example Miller, 1988; Mitroff *et al.*, 1987; Pauchant & Mitroff, 1988, 1990; P. Shrivastava *et al.*, 1988; D. Smith, 1990). Two interesting points emerge from the theories previously exposed and their following managerial developments: they are deeply rooted in a systemic perspective and give to ethics a central role for it helps targeting the deepest and most latent elements that could lead to a crisis.

A systemic perspective of the organization

To explain what a system is, I retain here the definition of Morin (2007, p. 11) for whom a system is "a relation between parts that can be very different from one another and that constitutes a whole at the same time organized, organizing and organizer". This definition is of particular importance as it summarizes the main characteristics of a complex system.

First, a system is composed of interrelated and diverse components, which interact and influence each other as well as the environment. An industrial organization, for example, can therefore be seen as a system for its multiple "components", both human and non-human, interact with each other while also interacting with other industries, clients, contractors, governments – the organizational environment.

But it is not just this interrelation that makes a system complex. Indeed, these relations are not static but are parts of a dynamic process of self-organization, giving a structure to the system, both hierarchical and non-linear (Cilliers, 1998; Heylighen, 1989). This organizing process is an intrinsic property of a complex system, which is extremely important as it allows new properties to emerge (Morin, 2007). For example, the capacity of production of an organization, may it be for physical products or services, is an emergent property of this organization, only possible through the organized interactions of its different parts. This is why, compared to a *complicated* system, a *complex* system cannot be understood by analyzing each of its parts independently.

This results in the well-known property that a complex system is more than the sum of its parts, both because of the interrelations and the emerging properties. But, as Morin (2007) underlines, a system is, *at the same time*, also less than the sum of its parts as some individual properties of the components will eventually be inhibited by the organization of the system. Individuals within an organization are part of a family, have hobbies, etc. These characteristics are usually inhibited by the organizational activity. The same observation can be made for technical components, as they are constrained to specific use while they could fulfill others. Furthermore, for living or social systems, the whole is integrated within its parts. The human body – a living system – is represented within each of its cells through the DNA. As well, don't organizations – social systems – usually want each employee to integrate its values?

Finally, a complex system is not isolated from its environment but dynamically interacts with it in a two-phase process. The system will evolve through self-organization – and therefore will increase its complexity[7] – as a response to its environment until reach a punctuated equilibrium, and then will also change this environment while being in a self-regulation phase (Gould & Eldredge, 1977; Heylighen, 1989). Let's take a simple example. Organizational activities have negatively impacted the natural environment. An environmental awareness has emerged, leading to new ethical and regulation standards, hence increasing the complexity of the legal and ethical environments of organizations. In response, most organizations have therefore integrated sustainable development strategies for example, thus increasing their internal complexity. This is illustrated by Figure 2.

[7] This is a corollary of the Ashby Law (1962) which states that a system must have a complexity at least equal to the system it controls.

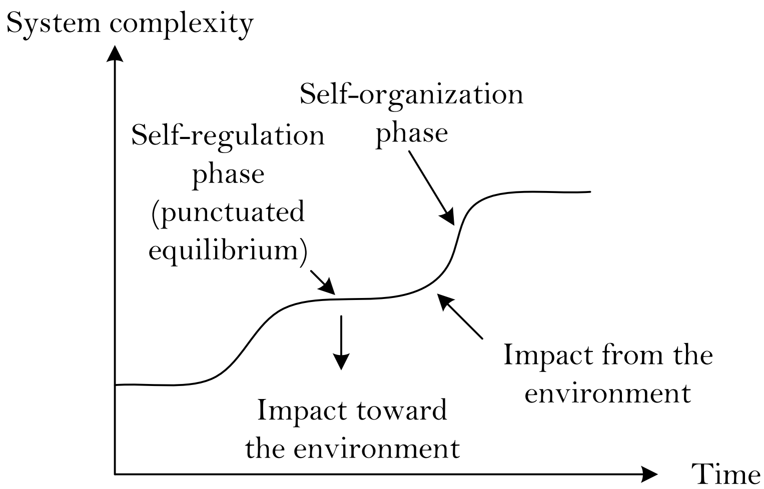

Figure 2. Cyclical phases of self-regulation and self-organization.

Therefore, there is a perpetual relation of evolution between the system and its environment. The understanding of the context in which the system evolves is then also very important (Woermann, 2013). But this is not an easy task, for the environment is both part of, and exterior to the system, which creates the ambiguous nature of boundaries between the system and the environment, better represented as a cloud of mist than a curtain.

This systemic perspective is at the base of the aforementioned crisis management theories, seeing the organization as "congeries of interdependent flows and activities linking shifting coalitions of participants embedded in wider material-resource and institutional environments" (Scott & Davis, 2007, p. 32). This approach allows considering the organization not only through its components, but also by the various interactions which exist, on the one hand, between each of them and, on the other hand, between them and the organizational environment (Roig, 1970). Therefore, a crisis can indeed be seen as an potential inherent property of the organizational system, either because the system itself will allow the emergence of the crisis (Turner, 1976), or because its interactive complexity cannot be perfectly understood, this limitation leading eventually to a crisis (Lagadec, 1981; Perrow, 1984; Reason, 1990).

Finally, day-to-day organizational activities may be, in themselves, problematic as the run for production and efficiency may also be a source of crisis (Fischbacher-Smith, 2014; Pauchant & Mitroff, 1990). A systemic perspective in crisis management is essential as it helps understanding the system dynamics. On the other hand, but in a complementary way, an ethical perspective helps target the elements within the system which may trigger a crisis.

Targeting the deepest roots of a crisis

The other aspect of peculiar importance that emerges from the classic theories presented above is the deep human and cultural dimensions of the crisis as well as the ethical aspect of crisis management. Even if the potential technical failures, the unsafe human actions or the natural forces are acknowledged and may be the active triggers of a crisis, the authors of the aforementioned theories agree to see human deviance[8] as the primary, long-term source of a crisis.

Explicitly for Weick (1987) and Reason (1990), the culture of the organization as a direct relation with this deviance capability, underlining with subtlety the ethical aspect of a crisis. Indeed, this notion of organizational culture is one of the well-known factors influencing the ethical behaviour of an individual (Treviño *et al.*, 2014). The positive and mutual influence between culture and ethics in organization has clearly been demonstrated (e.g. Benson & Ross, 1998; Guerci *et al.*, 2013; Ki *et al.*, 2012; Parboteeah *et al.*, 2010; Schminke *et al.*, 2005). Moreover, the consideration of several ethical issues are directly involved in crisis management, such as whistleblowing, corruption, pathological rationalizations (such as “crises are inevitable”, “crises cannot happen to us”, “everything is under control”, etc.) and moral disengagement, or a pathological pursuit of benefits (Guntzburger & Pauchant, 2014; Pauchant & Mitroff, 1992a, 1995; Pauchant & Parent, 2002). Explicitly for P. Shrivastava (1987a), crisis management is deeply ethical, for a disaster such as Bhopal cannot be accepted as the potential counterpart of an economic development, *a fortiori* when it is not the same individuals who share risk and benefits,

[8] In most of the literature, the word “failure” is usually used. I think this word is too binary, as either individual fails, or not. I suggest the word “deviance” is more appropriate as it illustrates the dynamic, incremental and often invisible slip of human actions which may, eventually, lead to a crisis. This is a central argument in the work of Vaughan (1997).

as explained before. Using a closely related argument, Beck (1992) denounces the lack of ethics in the risk calculus procedure, for it is the same individuals who create a technology and assess its risk, on behalf of a population which will – usually unconsciously and involuntary – accept it.

The presentation of the foundational theories in crisis management and their short analysis from a systemic and ethical point of view set up the context for this thesis but more importantly, they will serve as a basis for an analysis of the probabilistic methods used within the engineering field. This is the object of the second part of this chapter.

Questioning the limits of risk management in engineering

Why a focus on engineers? Engineers have certainly a considerable impact on the society as they conceived and operate energy production and distribution technologies, physical and chemical industrial processes, communication systems, transport infrastructure and vehicles, skyscrapers, medical equipment, and so on and so forth. By the very definition of their profession, they put science at the service of mankind[9]. Well aware of the potential disastrous consequences of their creations, they have elaborated numerous, highly sophisticated methods to try and prevent disasters. Nonetheless, industrial crises have increased, and their technical methods developed for risk management have been questioned.

Risk management approaches in engineering and their limits

First, an important distinction between *risk* and *hazard* has to be made, as both terms can be found in the engineering literature and are often used – wrongly – as synonyms. According to Wilson and McCutcheon (2003), a hazard is "the potential of a machine, equipment, process, material or physical factor in the working environment to cause harm to people, environment, assets or production" (p. XVII). Risk, on the other hand, is "the possibility of injury, loss or environmental incidents created by a hazard. The *significance* of risk is a function of the *probability* of an unwanted incident and *severity* of its consequences" (p. XIX, emphasis added). Therefore, a thorough identification of *hazards* and scenarios is a necessary precondition to an effective *risk* management (Crowl & Louvar, 2011).

This definition illustrates the very statistical mindset of risk management in engineering, based on a function of probability and severity of consequences. Numerous methods, especially in process or chemical engineering, have been developed on this approach using Bayesian inferences, modelling and decomposition of the process, and cause-consequence chain of event analysis. Such methods of hazard identification and risk assessment, which are not necessarily mutually exclusive but rather complementary, are,

[9] Engineering, as defined by The Encyclopedia Britannica is "the application of scientific principles to the optimal conversion of natural resources into structures, machines, products, systems, and processes for the benefit of humankind".

for the most popular: Fault Tree Analysis (FTA) and Event Tree Analysis (ETA), Simplified or Quantitative Risk Assessment (SRA or QRA), Bowtie Technique, Layer of Protection Analysis (LOPA), Hazard Identification and Hazard and Operability Studies (HAZID & HAZOP), What-if and Structured What-if techniques (SWIF), Probabilistic Risk Assessment (PRA) or Failure Mode and Effects Analysis (FMEA) (CCPS, 2008; Crowl & Louvar, 2011; Wilson & McCutcheon, 2003). Other safety-index-based methods such as Prototype Index for Inherent Safety (PIIS), Inherent Safety Index (ISI) and Integrated Inherent Safety Index (I2SI) or the Safety, Health, and Environmental (SHE) method are also available (Ahmad *et al.*, 2014).

These methods, extremely sophisticated for some, are particularly interesting from an engineering point of view, for they allow evaluating (quantitatively or qualitatively) technical risks, which certainly helps for communication, decision-making and comparison. They are usually integrated in a risk management process based on three main steps: 1- identification of hazards, 2- risk assessment and analysis and 3- decision (see Crowl & Louvar, 2011), the aforementioned methods being used for one or more steps. Each of those, however, as well as the general process, can be questioned.

Foremost, the identification of hazards may be limited in several ways. First, this step of data collection, is mostly based on the use of databases, surveys, inspection or failure reports, process reviews or controlled brainstorming (such as HAZOP) (Crowl & Louvar, 2011). It will be then limited by the trustworthiness and exhaustiveness of such sources. However, as it has been recently argued in the case of the Fukushima disaster (see Guntzburger & Pauchant, 2014), failure reports may not be systematically done, which undermine the reliability of this step. It is also strongly dependent of the individuals experience and the level of maturity of the technology or process. A misidentification may then results from a limited knowledge or comprehension of the process, a lack of previous identification – which has never been identified before as a hazard has strong chances not to be considered as such – or even a conscious rejection of weak signals, yet essential sources of information (Amalberti, 2013; Brizon & Wybo, 2009; Lagadec, 2012). This limitation has been recently recognized within the field of engineering risk management and improvements are proposed (see Paltrinieri *et al.*, 2014). Nonetheless, even if this is an interesting step forward, the solutions presented do not yet question, from a practical point of view, the probabilistic approach of risk assessment.

As stated before, the second step – risk assessment – is mostly based on a decomposition of the system, its modelling and/or a cause-consequence chain analysis. Therefore it will be limited by the accuracy of the model, or the elements considered in the sequential cause-consequence chain, which certainly does not take into account any social, cultural or political dimension. As explained in the first part of the chapter, organizations are part of a complex system and are themselves complex systems, which ask to consider them with a dynamic, global and non-linear interactive approach rather than a decomposition and causal one. Therefore, engaging with complexity directly question the validity of any models (Woermann, 2013). Indeed, when modelling, we try to capture the main representative features of the phenomena under study, which will be simpler than its actual complexity but hopefully sufficient to describe it in a useful way. That does not mean that we should not try to create models, as Woermann (2013, p. 40) explain:

> We should still perform the necessary calculations and make the necessary reductions, but we should recognize that such activities can lead to the development of useful models, not resolve the complexity.

Complexity science can help us getting a better understanding of complex systems (especially their structure) but not control them or predict perfectly their behaviours[10] (Cilliers, 2001; Nowotny, 2005). Furthermore, as it is the interactions which allow the system to evolve, using a linear and decomposition approach inherently discard any consideration of system evolution and deterioration. Even if technical risk assessments were perfectly valid, they would be so at a precise moment, under precise circumstances (technical, organizational, social, etc.) and they should therefore permanently evolve with them.

[10] I should here make the same warning as Bai and Banack (2006, note 8 p.17): I am not arguing for an indeterminist view of the reality but, adopting a complex point of view, I challenge a traditional approach based on reductionism and linear causality.

Considering complexity involves going beyond the reductionist approach of traditional science used in probabilistic models which implies that a system could be fully understood through the fragmented study of its component. A complex methodology will then reject the traditional reductionist assumptions defined by Allen (2000, 2001), which suppose 1- that the boundaries of the system are clearly known, 2- that clear and complete typologies exist to define and regroup all elements of the system, 3- that individual components could be defined by a homogeneous average and that their interactions are based on average parameters, and 4- that the system is stable or has reached an equilibrium.

This clearly explains why models used in probabilistic risk assessment methods are deeply limited when considering complex systems (Leveson, 2011; Murphy & Conner, 2012; Ramana, 2011; Topper & Lagadec, 2013). Although some authors have proposed ways for integrating other dimensions such as human and organizational factors (e.g. Cacciabue, 2000; Kariuki & Löwe, 2007; Targoutzidis, 2010)[11], even recent propositions regarding risk management within the field of engineering are based on this probabilistic paradigm (e.g. Ahmad *et al.*, 2014; Khakzad *et al.*, 2014; Paltrinieri *et al.*, 2014; Rathnayaka *et al.*, 2014).

Finally, the last step of the risk management process, decision-making, is also controversial. First, decisions are made based on the results of the technical methods which clearly may be limited, as argued before. Second, there is a double ethical issue, regarding the fact that a limited group of persons may accept some risk level about technologies developed by individuals sharing the same risk conception, on the one hand, and the fact they accept these risks on behalf of the society, may it be local or global, present or future, on the other hand.

This is, of course, one of the main points of Beck (1992) and it is well illustrated by this long, but worth-reading, reflection from van de Poel and Fahlquist (2012, p. 888)

> […] engineers may be said to be responsible for reducing risks to an acceptable level. What is acceptable, however, requires a

[11] Cacciabue (2000) still recognizes in his conclusion the limits of probabilities.

> normative judgment. This raises the question whether the engineer's responsibility for reducing risks to an acceptable level includes the responsibility to make a normative judgment on which risks are acceptable and which ones are not or that it is limited to meeting an acceptable risk level that is set in another way, for example, by a governmental regulator. The answer to this question may well depend on whether the engineers are designing a well-established technology for which safety standards have been set that are generally and publicly recognized as legitimate or that they are designing a radically new technology, like nanotechnology, for which existing safety standards cannot be applied straightforwardly and of which the hazards and risks are more uncertain anyway (for this distinction, see van de Poel and van Gorp (2006)). In the former case, engineers can rely on established safety standards. In the latter case, such standards are absent. Therefore in the second case engineers and scientists also have some responsibility for judging what risks are acceptable, although they are certainly not the only party that is or should be involved in such judgments.

This also involves the necessary distinction between safety and risk acceptability, the latter being directly influenced by the potential benefits of the system under analyze (Macpherson, 2008), point also denounced by Beck (1992), as well as P. Shrivastava (1987a) as discussed before. Indeed, decision-making is usually based on a utilitarian cost-benefits perspective as risks are accepted *because* there are potential benefits, for individuals or the society. Even if unconscious, the process of decision-making is influenced by ethical traditions and basic assumptions (Ersdal & Aven, 2008). As argued by Downer (2014), this would be less problematic if the result of the decision-making based on probabilistic methods were presented as contestable judgments rather than uncontestable truths, which is unfortunately very rarely the case. This triggers a blur between absolute and relative safety, the latter being often presented to society within official discourses as the former, which certainly helps for social acceptability, especially when official scientists and institutions are presented as the only legitimate voices (Tollefson, 2013).

This blur between absolute and relative safety is even present within the engineering community itself, embodied in the concept of inherent safety. Put simply, inherent safety is based on the idea that "what you don't have, can't leak", expression coined by Kletz (1978), the father of the concept. Such a design philosophy aims at either 1- eliminate the hazard at the source, 2- minimize the quantity of hazardous materials or 3- substitute it, 4- moderate the conditions of the process (temperature and pressure for example) or 5- simplify it (in this order of lesser safety) (Sutton, 2014). This approach is, of course, very relevant, but the expression itself "inherent safety" is somewhat misleading, as highlighted by Sutton (2014, p. 399).

This is especially the case for inherently safe nuclear reactors, for which safety relies on physics and chemistry rather than human interventions or technical devices (see Weinberg & Spiewak, 1984). As explained by Martin (2016), "at least in theory, this type of reactor can't suffer the kind of catastrophic failure that happened at Chernobyl and Fukushima, making unnecessary the expensive and redundant safety systems that have driven up the cost of conventional reactors". Would these reactors be inherently *safer* than conventional ones? Surely. But the complexity of nuclear energy technology and production invites us to be prudent and makes us wonder if such thing as an inherently *safe* nuclear reactor is possible. Therefore, "inherently safe" illustrates more the level of risk acceptability of nuclear scientists and engineers toward this technology than the actual level of safety or public risk acceptability (Herkert, 1994).

This strengthens the aforementioned idea that risk assessment and analyses are *subjective judgments* rather than *objective truths*, and that the whole process of risk management, from risk identification to data collection, communication, evaluation and to decision-making on risk acceptability is deeply value-laden (Mayo & Hollander, 1991; Roeser *et al.*, 2012).

Furthermore, these judgments are actually biased by the probabilistic methods themselves, for an event which has a very low probability of occurring may be not considered for prevention. Therefore, probabilistic approaches are some sort a self-fulfilling prophesies as Pauchant and Mitroff (1992a, p. 187) explained:

> What is wrong with these [probabilistic] procedures? Theoretically, nothing; morally, everything. Using these procedures almost always leads to the conclusion that nothing should be done. That decision has produced some of the worst disasters in history. Just a few weeks before the Exxon Valdez disaster, preparation for a large spill was discounted because the probability of occurrence was estimated at one in a million.
>
> The trouble with probability procedures is that they become self-fulfilling prophecies. Because some dangerous event has not occurred, it is initially assigned a low probability which is then seen as a vindication of the procedures themselves – a self-perpetuating trap from which there is no escape. Putting everything in probability terms has the almost inevitable result that one prepares for nothing.

To add another example, an analysis of the layers of protection (LOPA) of the Union Carbide's plant located in Bhopal before the night of December 3rd, 1984, would also conclude to one major gas leak in a million years (see Willey, 2014). Beyond technical aspects, the whole process of risk management is embedded in a broader organizational safety mindset which necessarily affects it. Therefore it can be easily overcome if the mindset of the whole organization – leaders included – is not already oriented toward preventive management, as illustrated by the Bhopal or Exxon Valdez disasters.

Current engineering risk management methods struggle then to deal with the complexity of industrial safety. Numerous dimensions are regularly discarded or ignored by these technical approaches. One may wonder what allows this lack of integrated knowledge regarding such a fundamental aspect of engineering. There is certainly no unique root cause to this complex issue, but professional fragmentation has surely, and strongly, contributed.

Professional specialization and fragmentation

According to the historical analysis of the sociology of knowledge made by Wilber (1995), the fragmentation of knowledge is linked to the development of modernity which prefigured the separation of sciences, arts and morality. This subject has been developed mostly with the work of Weber (1963)[12] that has been later pursued by Taylor (1985) and Habermas (1990) among others (Galvin & Todres, 2012). Such differentiation is mainly the result of a Cartesian heritage, in which science belongs to the cognitive realm, while art and morality belong to the realm of emotion and experience (Greendorfer, 1987). Based on the work of Wilber (1995), Galvin and Todres (2012) explain that this separation is the "dignity" – one of the most positive aspects – of modernity for it allows each discipline to evolve without the constraint of each other, hence creating space for specialization. For the authors, it is paradoxically also the "disaster" of modernity as such specializations have become dissociated from each other, fragmented, with an uneven development of each sphere. Nonetheless, as the authors argue, this differentiation should not be denied but acknowledged and honoured by integrating fundamental common concerns (p. 109):

> In postmodern times, we cannot simply turn back to a form of simplistic holism in a way that denies specialization and diversity. However, in honouring differentiation, we can, nevertheless, pursue such differentiated domains through an understanding of the fundamental non-separation of science, morality and the art of action in the way that life *moves*.

From a more managerial point of view, the potential dangers of specialization have been acknowledged long before Weber (1963) by Adam Smith, which is now considered as the oldest founder of the management thought and practice (Heames & Breland, 2010). Indeed, in his famous work *The Wealth of Nation*, A. Smith (1981, pp. 781-782) argued

[12] First published in 1920, in German.

that if specialization may trigger a gain in productivity, it could also lead to cognitive and subjective harms, such as alienation and detrimental work. More specifically, he warned that each profession, including managerial work and other specializations such as finance, law or engineering, necessarily “confines the views of men” and that it is only “when the mind is employed about a variety of objects [that it can become] expanded and enlarged” (A. Smith, 1979, p. 539).

While only the gain of productivity is usually emphasized from Smith’s work (see, for example Crowley & Sobel, 2010), several authors have nonetheless relayed this warning on fragmentation, arguing that it may be the source of crises (Pauchant & Mitroff, 1992b), of questionable ethical reasoning and practices (Toulmin, 1992) or of narrow ethical perceptions and practices (Baxter & Rarick, 1987, cited in Jackson et al., 2013). Similarly, Ghoshal (2005) has argued that following strictly management models can actually lead to unethical practices precisely because such models do not reflect the diversity and the complexity of the organizational reality and its interactions with the surrounding environment. Also, for Bai and Banack (2006), the determinist approach of traditional science has had disastrous ecological, social, economic and psychological consequences.

More recently, Wörsdörfer (2014) has argued that professional specialization is only a part of the process of fragmentation, for there is an upstream screening process wherein individuals will select a specialization consistent with their mindset. The author finally suggests that this fragmentation process has to be corrected for countering their anti-social effects, especially in management, economics and finance. However, it would be wrong to believe that fragmentation is an automatic consequence of specialization, as Greendorfer (1987) explains. For the author, fragmentation is the results of a lack of consensus or common focus on themes or issues, coupled with a vertical and isolated development of specialized disciplines. Therefore, fragmentation may be minimized by horizontal, cross-disciplinary integration.

Specifically for the engineering specialization, this fragmentation issue is well identified. For Richter and Paretti (2009), the profession suffers from disciplinary egocentrism. In their case study, they have observed that engineering students usually “fail to understand the value of multiple perspectives and approaches" (p.38). This failure, strengthen by their formation, limits their ability to address an issue with different point of views or to collaborate with individuals having a different point of view. As the authors explain (p. 38):

> Importantly, [this] lack of perspective is not only a rejection of other view points, but often [...] a failure to recognize differences in perspectives and contributions. Many of the students in this study, for example, ignored disciplinary differences in favour of simple attention to work habits [...]. This inability to recognize, much less accept, alternative perspectives also limits individuals' ability to integrate and synthesize differing epistemologies and value systems in addressing complex problems.

The same observations can be found in the work of O'Brien *et al.* (2003) and Downey (2005). For the latter, engineers become multidisciplinary despite their training rather than because of it. Moreover, because of their identity of technical problem solvers, the focus of their formation – and theirs after – is mainly on the technical aspect of a problem, while rejecting or omitting the human dimensions of problem definition and solving. Both for Downey (2005) and Richter and Paretti (2009), part of the solution may come from interdisciplinary integration in engineering education.

Interestingly, this interdisciplinary issue seems to be well recognized by the Canadian Engineering Accreditation Board (CEAB) or the Accreditation Board for Engineering and Technology (ABET) in the U.S., which validates national educational programs in engineering. For example, CEAB promotes team work and complementary studies (social sciences, art, management, communication, etc.), the later counting for at least 11% of the program (CEAB, 2014, p. 19). But such approach seems to present interdisciplinary as a peripheral tool, or a glaze, ornamenting the technical core of the formation rather than challenging it. The same observation can be made with the Grand Challenges for engineering, proposed in 2008 by the U.S. National Academy of Engineering (NAE)[13],

[13] See http://engineeringchallenges.org/challenges.aspx

wherein the need for deep critical reflexivity on the place and role of the engineers as they shape our modern society seems not to be perceived as one (Mitcham, 2014).

One last aspect of interest for this work resulting from the fragmentation of knowledge is the basic assumption structuring the conception of rationality in engineering: the fact that emotions are biases to rational judgments. This aspect is particularly present in the relation with public perceptions of risks, opposing rational objective expertise to emotionally biased public judgment (Coeckelbergh, 2009), as exemplified by this citation from Renn (1999, p. 3050), though the author is still in his article advocating for a deliberative process of risk management:

> Risk managers are faced with a difficult dilemma: On the one hand, technical expertise is a necessary but not sufficient condition for making prudent decisions on risk. On the other hand, public perceptions are at least partially driven by biases, anecdotal evidence, false assumptions about dose-effect relationships, and sensation (Okrent, 1998).

However, in many fields such has moral philosophy, psychology, ethnology, behavioural studies to name a few, it has been argued that emotions play an essential role in moral decision-making (e.g. de Waal *et al.*, 2009; Decety, 2009; Nussbaum, 2001; A. Smith, 2006 (1759)). Moreover, in the last decades, neuroscience has also shed new light on cognition by showing the deep interconnections between emotional and rational processes in decision-making, that is to say, the actual need of emotions for rational judgments (see, for example, Damásio, 1994; Okon-Singer et al., 2015; Pessoa, 2008).

In the field of risk management, several authors, rejecting this dichotomy between supposedly rational expert opinions and irrational – therefore irrelevant – emotionally biased public perceptions, have argued for the legitimacy of both perspectives, especially for risk acceptability (e.g. Herkert, 1994; Renn, 1999; Roeser, 2006, 2010, 2012b; Slovic, 2000; Stern & Fineberg, 1996). Specifically, Roeser (see Roeser, 2012a; Roeser & Pesch, 2016) has explained that moral 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 also argued that such emotions are a primary source of ethical reflections over risks peculiarly relevant for the work of engineers, which "should not be unemotional calculators [...] but work to cultivate their moral emotions and sensitivity, in order to be engaged in morally responsible engineering" (2012a, p. 103).

The technical perspective on risk in engineering, and its limitations, appears then to have emerged from the fragmentation of the engineering profession. As argued before, because of their highly technical education, they are trained to address and solve problems in technical terms, which influence their risk management practices. However, by doing so and because of their lack of integrative knowledge, they miss other fundamental dimensions. But as explained before, fragmentation of knowledge is paradoxical, as it has also permitted other disciplines to specialize and developed their own perspective on risks, enriching then our global understanding of the concept and creating what Funtowicz and Ravetz (1993, p. 739) have called a "plurality of legitimate perspectives" on risks (cited in Riesch, 2012, p. 89).

To summarize then, three major ethics issues have been identified so far in engineering risk management: the inconsistency between determinist and reductionist models versus the complexity of industrial reality, the subjectivity of the process of risk management and the legitimacy of a plurality of perspectives usually not accounted for, and finally the importance of emotional reflections towards risk acceptability. Hence, a way to empower engineers to address these identified ethics issues and to engage in a critical and creative reflections on their technical risk management practices, would surely to challenge them with a diversity of ethical perspectives on risks and safety relevant to these issues, but that they usually discard, neglect or simply ignore nonetheless.

Ethical pluralism and empowerment for better managing risks in engineering

Several authors, particularly in the business and medical ethics fields, acknowledging the complexity of the organizational world and the limited capacity of one unified ethical framework to grasp this complexity, have made a call for ethical pluralism (e.g. Buchholz & Rosenthal, 1996; Burton *et al.*, 2006; Hinman, 2012; Kovacs, 2010; McCarthy, 2006; Oosterhout *et al.*, 2004; Pauchant *et al.*, 2007). For Buchholz and Rosenthal (1996, p. 265), pluralism is:

> the view that no single moral principle or overarching theory of what is right can be appropriately applied in all ethically problematic situations. There is no one unifying, monistic principle from which lesser principles can be derived.

Ethical pluralism is an acknowledgement of the value of the diversity of ethical perspectives for providing an adequate moral ground in a complex world (Becker, 1992; Timmons, 2012). It is not, however, a call for an absolute relativism which would lead to inaction, but rather an understanding that for a specific moral issue, let's take safety, there is not one single valid answer. Different moral standards, convergent or eventually conflicting, may be relevant (Hinman, 2012). It is, then, more a call to what Perry (1970) named a committed relativism, an acknowledgement and a valorization of diversity, and yet, as a choice has to be made, a possible engagement toward a specific perspective or moral framework knowing that such commitment is fallible. This principle of fallibility is central to ethical pluralism. As Hinman (2012, p. 54) explains:

> Essentially, this principle [of fallibility] urges us toward moral humility – the realization that we might be mistaken in moral matters. No matter how strong our beliefs are, we might be mistaken. Consequently, we are always open to the possibility that we have to reconsider and revise those beliefs. Open-mindedness is the corollary of the principle of fallibility. This principle does not exclude commitments to theories, even deep

and passionate commitments. We may still have strong, deep beliefs, but we are always aware of the possibility that they might be mistaken or incomplete.

In a pluralistic view therefore, an ethical problem is an ill-structured problem, with no clear definition, and no simple, best solution. Any attempt to define the problem in sufficient details will be predetermined by a specific perspective (Hoffmann & Borenstein, 2013). Ill-structured problems are actually not unfamiliar to engineers. As Whitbeck (1995) has advocated, ethics problems are very similar to design problems in engineering: 1- there is no single best answer, 2- some solutions may be better than others but there are clearly unacceptable solutions, 3- because of their different advantages and drawbacks it is often hard to clearly decide between several good solutions, and finally, 4- solutions should achieve a desired end, be conformed to given specifications or criteria and be consistent with other, relevant, constraints (Vallero, 2011).

An ethical pluralism applied to safety engineering would then translate to the acknowledgement that several moral frameworks, may they eventually be conflicting with each other, are nonetheless relevant to this issue and that if a commitment is possible, this commitment is fallible and therefore open to reconsideration. This is what ethical risk management means in this thesis. Not a formal rejection of traditional, technical, approaches to risk management, but a need for moral humility and a recurrent critical reflexivity towards engineering safety practices.

What ethical frameworks, which would guide this process of critical reflexivity, could then be relevant? As explained before, pluralism is not relativism, all ethical perspectives are not equal in front of a specific issue, some are more relevant than others. Two classic traditions are already at the base of the ethical architecture of technical approaches for safety in engineering: deontology (as embodied in the first fundamental canon of the code of ethics for engineers: "Engineers, in the fulfillment of their professional duties, shall hold paramount the safety, health, and welfare of the public" (see NSPE, 2015)) and, as mentioned previously, utilitarianism. Based on the development made before, these two frameworks do not seem efficient to address the ethics issues emerging from the technical approaches to safety.

Therefore in this thesis, three other ethical perspectives, which are directly related to the limitations of the technical methods of risk management discussed before, are proposed:

- *The ethics of complexity*, mainly developed by Paul Cilliers (see Cilliers & Preiser, 2010), which offers a relevant ethical frame for addressing issues emerging from the application of complex thinking to safety;

- *The ethics of dialogue*, whose philosophical roots can be traced back to the discursive ethics of Habermas (1992) and which targets the plurality of legitimate perspectives discussed before (both from other disciplines and civil society);

- *The ethics of moral emotions*, echoing the moral philosophy of A. Smith (2006 (1759)) and Nussbaum (2001), which aims at addressing the moral legitimacy of emotional reflections regarding risks.

The relevancy of these frameworks is developed in article 2. Are those, however, the only ones relevant? Surely not. But I believe that diversifying ethical views of safety using those is a first step toward a relevant ethical pluralism in risk management.

Finally, it is not intended to limit this process of critical questioning to a philosophical activity. It is resolutely action-oriented and aims to empower engineers to address specific issues in their practice. In this study, the concept of self-efficacy (SE) is used as a proxy for empowerment. Indeed, as suggested by Ozer and Bandura (1990), self-efficacy strongly and positively influences personal empowerment. Therefore, an enhancement is SE should translate into a higher empowerment. SE is a major concept in behavioural science and is defined as the self-perceived capability of individuals to successfully achieve a desired action (Bandura, 1977). Individuals with a higher perception of their personal efficacy for a given action are likely to be more motivated and persistent in their engagement in such an action, and to set up for themselves higher standards of realization or outcome expectations (Bandura, 2001; Schunk, 1995). SE is not an immutable characteristic of an individual. According to Bandura (1977), it is influenced, among other factors, by performance accomplishment, own individual's or vicarious experiences, social persuasion or emotional arousal. Finally, training has been shown to efficiently and positively influence self-efficacy (Gist & Mitchell, 1992).

Analyses and experimental investigations in engineering education and practice

Research questions and objectives

Thereby, led by the theoretical development made before and using ethical pluralism first as an analysis grid and then as a driving force of improvement, it is proposed in this thesis to address two main general research questions:

To what extent current engineering education and practice empower engineers into an ethical approach of risk management?

How ethical pluralism applied to risk management could enhance this empowerment?

One may wonder why a focus on both education and practice. As reviewed by Trede *et al.* (2012), professional identity is a complex phenomenon influenced by both university and workplace learning. It is even more accurate for engineers, as, on top of practice itself, they are subject to continuing education and professional development throughout their career. Education therefore is not limited to few years at the university. Also, it has been argued before that engineers became multidisciplinary in spite of their formation rather than because of it (Downey, 2005). Such statement implies that practical experience helps challenging a fragmented point of view. Moreover, as this thesis focuses on risk management practices, it seems relevant to assess the influence of such experience on the perceived capability of individuals to engage them ethically.

A better understanding, based on empirical evidences, of the influence of 1- current engineering education and practice on the capability to engage risk management ethically and 2- the efficiency of a pluralistic ethical frame to improve such engagement, is surely a significant step towards better safety practices in engineering.

In order to provide some answers to the research questions presented before, and considering the time allowed to do so, several general research objectives have been set:

1. To analyze the nature of the relation between ethics and risk management in the engineering education literature;

    This objective is achieved in **article 1**;

2. To assess the influence of academic engineering education on a) assumptions regarding ethical aspects of risk management and b) the perception of capability (SE) to engage in an ethical approach of risk management;

3. To develop an educational method, based on ethical pluralism applied to risk management, and to assess its efficiency to enhance the perception of capability (SE) to engage in an ethical approach of risk management;

    These two objectives are achieved in **article 2**;

4. To analyze a) how risk management practice influences the perception of capability (SE) to engage in an ethical approach of risk management and b) how this perception might be related to assumptions regarding ethical aspects of risk management;

    This objective is achieved in **article 3.**

Table 1 summarizes key information on the three articles, including their specific research questions, key concepts, objectives and design, as well as their units of analysis and nature of data.

This thesis, by the combined contribution of these three articles, offers new practical insights on how ethics, and specifically ethical pluralism, through an appropriate educational approach and frame of analysis, may favourably contribute to potentially more responsible engineering practices. A detailed discussion of each article contributions to the engineering risk management field is presented in conclusion of this thesis

.

Table 1. Summary presentation of the thesis articles

	Article 1	Article 2		Article 3
Title	Ethical Risk Management Education in Engineering: A Systematic Review	Empowering Engineering Students in Ethical Risk Management		Professional Ethnocentrism and Ethical Risk Management Efficacy: The Mediating Role of Emotions Among Engineers
Research question(s)	*What is the nature of the relation between ethics and risk management in the engineering education literature?*	*To what extent does academic engineering education influence perspectives on ethical aspects of risk management?* *To what extent does academic engineering education influence the perception of capability (SE) to engage in an ethical approach of risk management?*	*How to enhance, using a pluralistic ethical perspective of risk management, this perception?*	*To what extent does the self-perception of individual's abilities to ethically approach risk management influences professional ethnocentrism?* *What is the role of emotions in this relation?*
Key concepts	Risk management, Engineering Ethics, Engineering education	Academic engineering education, Ethical risk management, Ethical pluralism, empowerment, self-efficacy		Multidisciplinary, public deliberation, Emotional awareness Ethical risk management efficacy
Research Design	Systematic literature review	Questionnaire	Participatory action research (workshops) and survey	Questionnaire
Unit of analysis	Relation between ethics and risk management	First and last year students	Group of workshop students	Professional engineers (as individuals)
Data	Scientific articles	Quantitative answers to survey	Quantitative answers to survey and group interviews	Quantitative answers to survey
Article Status	Published in *Science and Engineering Ethics* (DOI: 10.1007/s11948-016-9777-y)	Submitted to *Engineering Studies*		Submitted to *Safety Science*

A note on methodology

As each article focuses on different aspects of the research, a detailed methodology section is presented within each of them. However, some aspects or explanations regarding the research design are not included and are therefore addressed hereafter.

Choice of method and design

If the choice of a systematic literature review to analyze the nature of the relation between ethics and risk management in the engineering education literature or the use of a questionnaire to assess the influence the academic engineering education or risk management practice seems relatively obvious, the choice of a participatory action strategy deserves perhaps some explanations.

As one aspect of this research is to propose an educational method to enhance self-efficacy in ethical risk management, this method, of course, has to be tested. A specific problem is addressed in a specific community from which feedback is requested. The research strategy of choice is then action research (Patton, 2002, p. 221), and more specifically, participatory action research (Kemmis & McTaggart, 2000; Macdonald, 2012). Indeed, as this research seeks for an improvement of the risk management practices within the engineering profession, their participation is essential. Engineers are not so much passive subjects of this study than active contributors (Macdonald, 2012), at least for this part. The proposed method is therefore based on workshops using an active learning, for such an approach has been suggested to be an efficient educative method in engineering (see Felder *et al.*, 2000; Prince, 2004). Details on the construction of each of the workshops are given in article 2.

Questionnaire construction and validity

For articles 2 and 3, an online survey was necessary to assess perspectives on several ethical dimensions in risk management and ethical risk management self-efficacy, both for students and professional engineers. The survey was hosted by an independent server[14] and is presented in Appendix A. The same questionnaire has been used to analyze the

[14] www.unipark.com

efficiency of the workshops, but questions regarding perceived usefulness, relevance and comfort during these workshops have been added. Perspectives toward ethical issues have been assessed through the level of agreement toward randomized statements. This level, as well as the self-efficacy, has been measured using a five-point Likert scale.

Two parameters are important to assure the quality of the instrument: the reliability and the validity. The reliability of the instrument, assessed using the concept of internal consistency (Cronbach's alpha), is directly addressed within articles 2 and 3. The validity of a questionnaire is usually analyzed using three types of validity: criterion validity, content validity and construct validity (Bohrnstedt, 2010).

Criterion validity refers to the possible relation between the constructed measure and a form of external behaviour existing presently (concurrent validity) or being a future outcome predicted by the measurement (predictive validity) (Bohrnstedt, 2010; Nunnally, 1978). The first part of the questionnaire developed for this study aims at measuring a level of agreement, or opinions, towards specific ethics-related dimensions of risk management. The purpose is not to predict or to connect to specific behaviours using this measure, therefore analysis of criterion validity is irrelevant for this part. It is, however, relevant for the self-efficacy scale, for it has been specifically developed to understand and predict behaviour. Although the criterion validity of the scale developed in this study has not been evaluated directly, as no measurement of current, related, behaviour has been made, such validity is, however, well established in the literature for other self-efficacy scales (e.g. Berry *et al.*, 1989; Chesney *et al.*, 2006; Rowbotham & Schmitz, 2013; Sherer & Maddux, 1982).

Content validity refers to the capacity of the instrument to adequately cover a specific domain of meaning. This validity is quantitatively assessed by the researcher or the research team. There is usually no strict criteria for analyzing content validity, but Bohrnstedt (2010, p. 375) gives nonetheless two guidelines: the development of the instrument should be based on 1- a careful search of the literature, and 2- reflections on how personal observations and insights from the researcher refer to additional dimensions. Both scales developed in this study (agreement on ethical dimensions of risk management and self-efficacy) are based on a thorough literature analysis and feedback from researchers associated to the Chair in Ethical Management HEC Montreal. The development of the self-efficacy scale has also been based on recommendations from Bandura (2006) to enhance content validity. Two rounds of pre-tests have also been executed. The first has been made with 23 professional engineers (personal relations) and feedback was obtained directly within the questionnaire. The second with 16 engineering students to which I was lecturing at that time (pretest authorized by the university administration) and feedback was obtained during a discussion session after class. These pre-tests have allowed for verifying the variance generated by the survey, as well as adding, rewriting or clarifying several items.

Finally, construct validity refers to the capacity of the instrument to actually measure the theoretical constructs under study, and can be analyzed using both exploratory and confirmatory factor analysis (Bohrnstedt, 2010). Such analysis have been executed using STATA or SPSS and results are discussed both in articles 2 and 3.

Research site access and data sampling

As explained in article 2, data for this part of the study have been gathered from one engineering school only. This decision was one of convenience. Indeed, in order to achieve this research, I had to contact every first and last year students in the selected engineering school, regardless of the speciality. Students from the second and third years have not been contacted since I was not interested to analyze the influence of engineering education on a yearly basis. This access had to be officially granted and eased by the administration of the selected university. Understandably, this has been peculiarly difficult, even though I had personal access to this administration, and has required several contacts. Students recruiting has therefore been made by e-mail, using the official mailing lists provided by the administration. Participation was on voluntary base only, and fully anonymous.

The fact that this study focus on only one university is, of course, an important limit to the generalization of the analysis, but it would have been difficult to replicate this research in other universities considering the time allowed. However, as engineering programs are certified by CEAB throughout the country using the same criteria, it is reasonable to hypothesize that programs are relatively similar.

Regarding article 3, access to a large number of professional engineers also was a major challenge and has been possible thanks to the alumni association of the university from article 2. Professional engineers have therefore been originally recruited by the association itself, regardless of their speciality and experience. This process also took time and required many contacts. However, it is not possible to state that data are only from engineers being part of this association, as the research invitation has been relayed by third parties, such as the CRAIM (Conseil pour la Réduction des Accidents Industriels Majeurs)[15].

Ethics approval

Original ethics approval from the Research Ethics Board (REB) has been granted June 22nd, 2015 (Project N°2016-1812) and renewed May 02nd, 2016. As part of the research took place in an engineering school, ethics approval has also been granted from the REB of the host institution.

[15] http://www.craim.ca/

CHAPTER 1.

ETHICAL RISK MANAGEMENT EDUCATION IN ENGINEERING: A SYSTEMATIC REVIEW (ARTICLE 1)

Article presentation

The previous theoretical framework has allowed to establish the relevance to bridge risk management and ethics in engineering, and to wonder to what extent current engineering education and practice empower engineers to actually make this link. Before anything else, the first natural step to answering this question is to analyze what is said about such a relation in the engineering education literature.

The assumption that justifies this analysis lies on one of the *raisons d'être* of academic literature, that is to say to contribute, with more or less delay, to the educational content within a given field, so that a portrait obtained through literature analysis will give a more or less accurate representation of what it is actually done in the classroom. This seems even more accurate in this case, since it is specifically the literature about education that is targeted.

The following article, published in *Science and Engineering Ethics*, presents therefore an analysis of the nature of the relation between ethics and risk management in the engineering education literature using a systematic review. Such a methodology has been selected for its robustness, since it is replicable thanks to an explicitly stated and transparent research strategy.

Abstract

Risk management is certainly one of the most important professional responsibilities of an engineer. As such, this activity needs to be combined with complex ethical reflections, and this requirement should therefore be explicitly integrated in engineering education. In this article we analyse how this nexus between ethics and risk management is expressed in the engineering education research literature. It was done by reviewing 135 articles published between 1980 and March 1, 2016. These articles have been selected from 21 major journals specialized in engineering education, engineering ethics and ethics education. Our review suggests that risk management is mostly used as an anecdote or an example when addressing ethics issues in engineering education. Further, it is perceived as an ethical duty or requirement, achieved through rational and technical methods. However, a small number of publications do offer some critical analyses of ethics education in engineering and their implications for an ethical risk and safety management. Therefore, we argue in this article that the link between risk management and ethics should be further developed in engineering education in order to promote the progressive change toward more socially and environmentally responsible engineering practices. Several research trends and issues are also identified and discussed in order to support the engineering education community in this project.

Keywords: Risk management, safety, engineering ethics, engineering education, systematic review.

1.1. INTRODUCTION

In society, engineers play a central role as they build physical and chemical processes, communication systems and technologies, transport infrastructure and vehicles, skyscrapers, medical equipment, to name a few. Such a role necessarily entails great responsibilities toward society and the environment, and its impacts must be adequately managed. Risk management[16] should thus be included in any engineer's education, as suggested by CCPE (Amyotte & McCutcheon, 2006). As for responsibility, beyond its legal aspect and its social connotation, this concept refers directly to ethics, which is another fundamental element of engineering practice and education. This ethical aspect is taught using different methods and approaches possibly leading to mixed results (Keefer *et al.*, 2014). Therefore, the two notions of risk management and ethics are essential in engineering education and are specifically addressed, directly or indirectly, in accreditation criteria of engineering programs in the US (ABET, 2015) and Canada (CEAB, 2014).

The notion of responsibility clearly bridges risk management and ethics. Also, an effective risk management program can be seen in itself as an ethical activity (Crandall *et al.*, 2013; Guntzburger & Pauchant, 2014; Pauchant *et al.*, 2008; Pauchant & Mitroff, 1992, 1995). Nonetheless, we argue that it is not sufficient to manage risk to become ethical. Risk management still has to be performed *ethically*. Numerous authors in social sciences and engineering have analyzed the ethical limits of methods traditionally used for risk management in engineering: the inequity in risk distribution and acceptability (Beck, 1992; Shrivastava, 1987), the over-confidence on rational calculus (Beck, 1992; Pauchant & Mitroff, 1992), the necessity to consider complex organizational, historical and social context (Guntzburger & Pauchant, 2014; Leveson, 2004), the low consideration for weak signals (Brizon & Wybo, 2009) or public perception (Herkert, 1994), the limits of decomposition, modelling or determinism (Cilliers & Preiser, 2010; Murphy *et al.*, 2011)

[16] In this paper, the term risk management refers to the process of risk analysis (identification, estimation and evaluation) as well as activities managing this process (planning, controlling, administrating, etc.). See Frosdick (1997) for an explanation of the difference between management of risk (risk analysis) and risk management.

and objective judgments (Downer, 2014; Macpherson, 2008) are just a few, but relevant, examples.

Following these authors, we argue in this article that ethics should not only be a reason for doing risk management, but that it should also be used as a powerful educational and professional asset, allowing critical evaluation and reflection, in order to improve risk management methods. Moreover, as education is the base for improvement of engineering practice, we believe that this deep systemic relationship between ethics and risk management should be reflected in engineering education.

The connection between risk management and ethics is not new. The field of engineering ethics is particularly concerned by the societal and environmental implications of the profession. Numerous studies, through macro-ethical reflections, address this issue. Moreover, the dialogue with the STS community enriches this field (Herkert, 2005, 2006). On this question, Science and Engineering Ethics (SEE) has published a special issue on risk and responsibility in 2010 (Volume 16, Issue 3). As well, the issue of ethics education has been the object of numerous studies, analyzing how it can be efficiently taught, or if it should be taught at all (see, for example, Abaté (2011), for a discussion on this question). SEE has also recently devoted a special issue on the question of teaching social responsibility in science and engineering (Volume 19, Issue 4, 2013). Therefore, in our work, we aim to analyze how this nexus between ethics and risk management is addressed in the engineering education research literature. In order to meet this objective, we show here the results of a systematic review of relevant papers in the field, published between 1980 and March 1, 2016.

Systematic reviews are built on an explicitly stated and transparent methodological strategy. It is replicable, and it differs in that way from narrative reviews (Tranfield *et al.*, 2003, p. 209). This rigorous process is based on four principles: the review has to be 1- systematic and organized according to a method designed specifically to address the review or research question; 2- transparent and explicitly stated with clear inclusion and exclusion criteria; 3- replicable and updatable thanks to the sufficient level of detail given by the researcher and 4- synthesized (Briner & Denyer, 2012). The next section explains in detail the methodology used for this systematic review.

1.2. METHODOLOGY

1.2.1. The Research Framework

For this review, we opted to focus on journals rather than the topic, since several relevant academic journals are not referenced in general databases or search engines such as ProQuest or Engineering Village. Journals were then qualified as relevant if their focus was on higher engineering education, engineering ethics or ethics education. Journals focusing on engineering education were identified using the work of Van Epps (2013, 2014) who created a list of 21 journals specifically addressing this issue. She did it using an overall ranking scheme including the impact factor (ISI), SCImago Journal Ranking (SJR), h-index (Google Scholar)[17] and open access. In our study, the *Journal of Pre-College Engineering Education Research* was excluded from this list because its focus is not on higher education. As well, *Engineering Education: A Journal of the Higher Education Academy, Journal of Applications and Practices in Engineering Education* and *Australasian Journal of Engineering Education* were passed over because their website or search engine were unable to load or they returned server error at the time of this research.

Of course, considering the relevance of risk management for chemical and process engineers, *Education for Chemical Engineers* was added in our selection. Also, in order to cover the field of engineering ethics and ethics education, *Science and Engineering Ethics*, *Ethics and Education* as well as *The International Journal of Ethics Education* were added as their focus is specifically on engineering ethics, or on ethics education. Table 2 regroups the sample of the 21 journals selected for this systematic review. It shows their impact factor and SJR index when available.

[17] The Impact Factor (IF) is usually used as a proxy of the importance of a journal in a specific field, while the SCImago Journal Rank (SJR) measures its prestige and the h-index, its productivity (see, for example, Bornmann *et al.*, 2012 for details).

Table 2. List of selected journals with their impact factor and SJR index (2014 - when available)

Title	Impact factor	SJR index
Advances in Engineering Education (AEE)	-	0.23
American Journal of Engineering Education (AJEE)	-	-
Education for Chemical Engineers	-	0.31
Engineering Studies	0.5	0.38
Ethics and education	-	0.22
European Journal of Engineering Education (EJEE)	-	0.42
Global Journal of Engineering Education (GJEE)	-	0.18
IEEE Transactions on Education	0.84	0.68
International Journal of Collaborative Engineering (IJCE)	-	-
International Journal of Continuing Engineering Education and LifeLong Learning (IJCEELL)	-	0.18
International Journal of Engineering Education (IJEE)	0.58	0.31
International Journal of Engineering Pedagogy (iJEP)	-	-
International Journal of Engineering, Social Justice and Peace	-	-
International Journal of Quality Assurance in Engineering and Technology Education (IJQAETE)	-	-
International Journal of Service Learning in Engineering (IJSLE)	-	-
Journal of business ethics education	-	-
Journal of Engineering Education	2.06	1.7
Journal of Professional Issues in Engineering Education and Practice	0.27	0.45
Science and Engineering Ethics	0.96	0.42
The Online Journal for Global Engineering Education (OJGEE)	-	-
World Transactions on Engineering and Technology Education (WTE&TE)	-	0.19

1.2.2. The Identification of Articles

Within these journals, relevant papers were identified through semantic analyses. The selection of specific terms was not obvious as many concepts refer to the process of risk management, such as risk identification, risk assessment, risk analysis, risk evaluation, awareness of risk, safety management, etc. Furthermore, risk and hazard are (unfortunately) often used interchangeably (Amyotte & McCutcheon, 2006). Therefore, search queries were based on the following terms: “risk”, “hazard” and “safety” along with their derivatives using the star (*) operator. These terms were chosen for their important recurrence in the field of risk and safety management and should therefore be useful to identify most, if not all, of the relevant articles. Note that the term “security” is sometimes associated with risk management, but has been excluded from our research as it refers mostly to “risks originating from or exacerbated by malicious intent” (Piètre-Cambacédès & Bouissou, 2013) which is not the focus of our review. For the ethics field, the term “ethic” and “responsibility” along with their derivatives were chosen. As well, “professionalism” was selected as this term encompasses clearly the ethical dimension of the engineering profession (Harris, 2008).

For *Science and Engineering Ethics*, the terms “education”, “teach” and “curriculum” and their derivatives were searched independently in articles’ title and abstract. As well, the term “engineer” and its derivatives were looked for in article titles. This strategy allowed us to target papers addressing specifically engineering education issues. As well, for *Ethics and Education* and *The International Journal of Ethics Education*, the keyword “engineer” and its derivatives were added in the search within titles. Finally, the search scanned every paper available online for each journal, as no time range was specified. This research was made during summer 2015 and was updated in February 2016. Therefore, no article published after March 1, 2016, has been considered for this review.

To be relevant, identified papers had to show their prime focus on risk management or in ethics. Therefore, once journals and specific terms were determined, the strategy for identifying relevant papers was based on a five-step process: 1- a first sweep was made searching for “risk*”, “hazard*” or “safe*” in article titles. 2- Among the previously identified articles, “ethic*”, “responsib* or “professionalism” were searched in the title and 3- in the text. These three steps allowed for the identification of risk management papers coupling ethical concepts. The last two steps consisted in an inverted search: 4- “ethic*”, “responsib*” or “professionalism” were looked for in articles’ title and 5- within these articles, “risk*”, “safe*” or “hazard*” were searched in the text to identify papers coupling ethics and risk management. Only original research papers were considered for this review. Hence, commentaries on articles, editorials, or student essays were not taken into account.

To summarize, Table 3 regroups the search strategies used to identify articles in each category: 1- Main focus on risk management, 2- Main focus on ethics, 3- Main focus on both risk management and ethics, 4- Main focus on risk management with coupling with ethics and 5- Main focus on ethics with coupling with risk management.

Table 3. Selected search strategies for each article category in the engineering education

Category of article	Research strategy
1 - Main focus on risk management	(risk* OR hazard* OR safe*) IN title
2 - Main focus on ethics	(ethic* OR responsib* OR professionalism) IN title
3 - Main focus on both risk management and ethics	[(risk* OR hazard* OR safe*) IN title] AND [(ethic* OR responsib* OR professionalism) IN title]
4 - Main focus on risk management with coupling with ethics	[(risk* OR hazard* OR safe*) IN title] AND [(ethic* OR responsib* OR professionalism) IN text]
5 - Main focus on ethics with coupling with risk management	[(ethic* OR responsib* OR professionalism) IN title] AND [(risk* OR hazard* OR safe*) IN text]

Using this approach, a dataset of 243 potentially relevant articles was first created. But since the main purpose of this article was to analyze relevant connections made between risk management and ethics in the engineering education, only the content of articles within categories 3, 4 and 5 was then thoroughly analyzed. This gave us an initial sample of 157 articles. Among these, a quick search was made to verify the relevancy of the connections. 22 off-topic papers[18] were identified and discarded, leading to a final corpus of 135 relevant articles. The number of relevant articles for each category and each selected journal is presented in Table 4. References for these articles are presented in Table 6 and 7 within the Appendix.

[18] Articles in which keywords of ethics or risk management are mentioned but with another meaning (ex. "the risk of a student to fail an ethics course", "with their grade at risk", "it is the ethical duty of the university to assure the safety of students", etc.)

1.2.3. The Content Analysis

The strategy used for the content analysis of the 135 selected papers was based on a four-step process: 1- classification of the articles stemming from the search strategy, 2- determination of the nature of the coupling between risk management and ethics, 3- second classification of the selected articles according to the identified nature of this coupling and 4- analysis of all the articles.

The first step was a direct result of the search strategy. As presented in Table 4, no article was identified as having a main focus on both concepts of risk management and ethics in the selected journals. Therefore, two categories remained for analysis: 1- articles with prime focus on risk management and a coupling with ethics and 2- articles with prime focus on ethics and a coupling with risk management.

The second and third steps were used to assess the nature of this coupling and to classify articles in 3 new subcategories:

1- *Anecdotal or illustrative*: search terms of ethics or risk management are mentioned once or twice within the text, mainly for illustrative purpose in an example or a citation with no analysis or discussion of the link between the two concepts;

2- *Duty, responsibility or requirement*: search terms of ethics or risk management are mentioned several times, in a sense of professional or educational issues, or responsibilities (reference of curriculum criteria such as ABET or CEAB, or professional codes, safety as an ethical issue, responsibility to develop safe technology, necessity to add ethical knowledge to technical knowledge, etc.) with no questioning or analysis on the relation between these two concepts;

3- *Ethical risk management*: search terms of ethics or risk management are often mentioned, and the link between the two concepts constitutes an important part of the article. The connection is made in a context of a discussion of methods or ethical analysis of risk management, educational approaches, or content of risk management teaching and approaches.

In the following sections, descriptive results will be presented first, next will come the content analysis itself which then lead to a discussion of these findings.

1.3. THE FINDINGS OF THE SYSTEMATIC REVIEW

This section presents some descriptive results regarding the nature and the evolution of publications focusing on risk management, ethics and their connection in the engineering education literature. Later on, a summary of the general findings, resulting from the content analysis of articles bridging ethics and risk management, will be presented and discussed.

1.3.1. Descriptive Findings

Quantitative Results

Table 4 shows some relevant descriptive results. The first important observation is that there is no article within our selected journals for which the main focus is both on risk management and ethics. We look upon this fact as a first element illustrating the lack of explicit relationship between risk management and ethics in engineering education literature. This will be developed in the next section.

Table 4. Number of article for each category in engineering education and each selected journals (ranked according to their impact factor)

Title	Main focus on risk management	Main focus on ethics	Main focus on both risk management and ethics	Main focus on risk management with coupling with ethics	Main focus on ethics with coupling with risk management
Advances in Engineering Education (AEE)	1	0	0	0	0
American Journal of Engineering Education (AJEE)	0	0	0	0	0
Education for Chemical Engineers	6	3	0	5	3
Engineering Studies	2	3	0	2	3
Ethics and education	0	0	0	0	0
European Journal of Engineering Education (EJEE)	8	27	0	3	16
Global Journal of Engineering Education (GJEE)	2	4	0	0	2
IEEE Transactions on Education	7	9	0	1	4
International Journal of Collaborative Engineering (IJCE)	0	0	0	0	0
International Journal of Continuing Engineering Education and LifeLong Learning (IJCEELL)	1	1	0	0	0
International Journal of Engineering Education (IJEE)	4	20	0	0	2
International Journal of Engineering Pedagogy (iJEP)	0	1	0	0	1
International Journal of Engineering. Social Justice and Peace	0	4	0	0	4
International Journal of Quality Assurance in Engineering and Technology Education (IJQAETE)	0	0	0	0	0
International Journal of Service Learning in Engineering (IJSLE)	1	1	0	1	0
Journal of business ethics education	0	0	0	0	0
Journal of Engineering Education	3	28	0	3	22
Journal of Professional Issues in Engineering Education and Practice	4	24	0	3	20
Science and Engineering Ethics	0	49	0	0	37
The Online Journal for Global Engineering Education (OJGEE)	0	0	0	0	0
World Transactions on Engineering and Technology Education (WTE&TE)	7	1	0	2	1
Total	**46**	**175**	**0**	**20**	**115**

Secondly, it appears that despite the effort of some authors (e.g. Van Epps, 2013) to propose alternative publishing venues for articles in engineering education, more than half of the 221 selected articles (55%) have been published in 4 journals (JEE, JPIEEP, IJEE & EJEE). Moreover, one can see that more articles addressing ethics in engineering education are published in a journal specialized in engineering ethics (22% - SEE) rather than in engineering education (14% - JEE) despite its higher impact factor.

This may be interpreted in several ways. First, there are more journals addressing the issue of engineering education than engineering ethics. Therefore, if authors still want to publish in high-ranking journals, they might not necessarily choose the one with the highest impact factor, illustrating the changing role of this criterion for journal selection (Lozano *et al.*, 2012) and resulting in a spread of publications. Second, we have been more restrictive in our search within journals which are specialized in education (search of ethics terms in title) rather than within those specialized in ethics (search for education terms in title and abstract). Therefore, if several papers identified in SEE address the issue of engineering education, it is often not their prime focus. This result will be further analyzed in the final discussion.

Another interesting result is the presence of a larger number of publications targeting ethics in engineering education rather than focusing on risk management. This larger number of publications covering ethics certainly illustrates the increasing importance of this field in engineering education as well as the diversity of approaches, as observed and analyzed recently by Keefer *et al.* (2014). Despite the smaller number of publications regarding risk management in engineering education, a diversity of topics is also present such as, for example, theoretical reflections (Ward, 2006, 2007, 2013, 2014), analysis of curricula or courses (Gute *et al.*, 1993; Langdon *et al.*, 2010; Perrin & Laurent, 2008; Petersen *et al.*, 2008) and the development of specialized courses using multidisciplinary approaches (Hashash *et al.*, 2012; McKnight *et al.*, 1996). Pedagogical methods are also proposed such as case studies (Bignell, 1999; Dembe, 1996; Shallcross, 2013a), concept maps (Shallcross, 2013b, 2013c), safety shares (Shallcross, 2014), online (Keren *et al.*, 2011) or in-class modules (Noakes *et al.*, 2011) and web portal (Redel-Macias *et al.*, 2015). Despite this diversity of approaches and methods, this situation may illustrate that there is a wider consensus between the academics in regards to the nature of risk management and ways to address it in engineering education as compared to ethics.

Finally, it seems that risk management in engineering education is more often discussed without relation with the ethical dimension of this activity (only 44% of articles focusing on risk management present a close or loose coupling with ethics) rather than the opposite (where 66% of articles focusing on ethics present a more or less important connection with risk management). This is not surprising though, as this relation is formally stated in the first fundamental canon of engineers' code of ethics: "Engineers, in the fulfillment of their professional duties, shall hold paramount the safety, health, and welfare of the public" (see, for example, NSPE, 2015). However, this less frequent connection with ethics in risk management papers also illustrates that risk management is considered, within the engineering education body of literature, as a technical activity for which no ethical questioning is necessary.

Field Evolution

On its primary axis, Figure 3 shows the evolution of the number of published articles for each identified category, from 1980 to March 2016.

The first article identified is from Kline (1980) and it focuses on ethics. It is a tribute to the social views of electrical engineer Charles Proteus Steinmetz (1865 – 1923) and their implications for engineers' education. However, no discussion on risk management is presented. The first article focusing on ethics while addressing some notions of risk is from Gunn and Vesilind (1983), and is a discussion on how to implement ethics education in an engineering curriculum. The first article focusing on risk management is from Tittes (1983). In his paper, the author addresses the importance of integrating safety education in the engineering curriculum, although without mentioning a relation with ethics. The reasons why these articles appear in this period are non-obvious – none of them directly refer to a specific industrial accident for example –, but the formalization of the responsibility of the engineer in its code of ethics in mid-1970 could be one of them (see, for example, Russell and Stouffer (2003) for a historical analysis of the ASCE Code of Ethics). It is not until the beginning of 1990 that we see the first identified article connecting – anecdotally, through a mention of the Code – risk management with ethics (see Gute *et al.*, 1993).

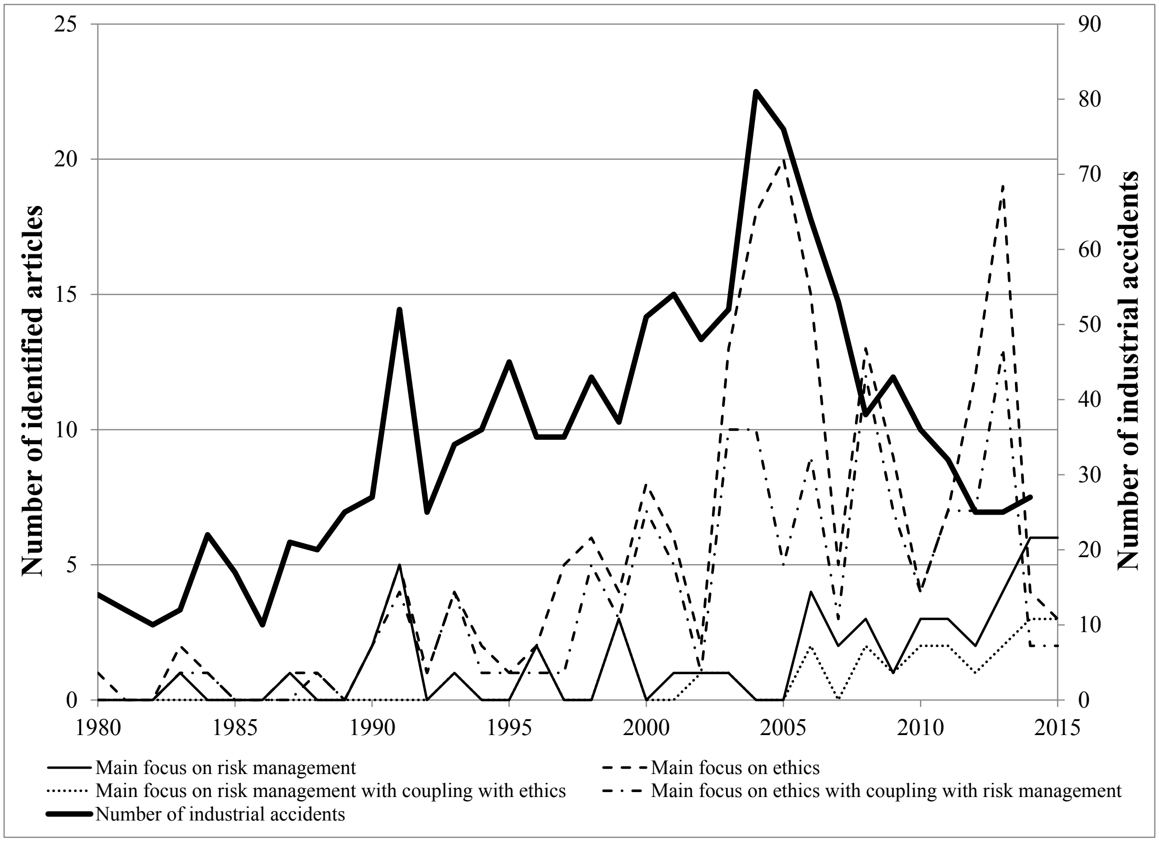

Figure 3. Number of article for each identified article category from 1978 to 2015 and number of industrial accidents for the same period (EM-DAT Database, Guha-Sapir et al., 2015) (secondary axis).

Figure 3 demonstrates that there is an increasing focus on risk management, ethics and their connection in engineering education literature. This figure also represents, on its secondary axis, the evolution of industrial accidents for the same period[19]. It is very interesting to observe that even though industrial accidents might not have triggered the publication of the first articles analyzed, there is a strong correlation between the evolution of the number of our identified articles and the number of industrial accidents for the same period. This is particularly significant for articles focusing on ethics (*p_value:* 0.0000, R^2: 0.47) and those among these addressing risk management concepts

[19] Those data were gathered from the EM-DAT database, available online (see Guha-Sapir *et al.*, 2015).

(*p_value:* 0.0003, R^2: 0.32), while it is not significant for articles focusing on risk management (*p_value:* 0.32), and those among these addressing ethics (*p_value:* 0.53).

These results illustrate once again the strong concern, within the engineering education community, about the responsibility of engineers toward society and the importance of addressing this issue in engineering education. Nevertheless, it also illustrates that this preoccupation is mainly addressed through ethical approaches or questioning – which are, of course, essential – without embedding them in the education of risk management. We believe that such an approach runs the danger of strengthening the knowing-doing gap, regularly criticized in the literature (Nielsen, 2010, 2014), and the danger of limiting the progressive change of the profession toward more responsible practices.

Engineers certainly know they have to be socially and environmentally responsible. But can they act accordingly when the technical tools used for risk management practices might be questionable from an ethical standpoint? Indeed, and as mentioned in introduction, traditional methods used in engineering for risk management are ethically limited when dealing with complex socio-technical systems (Beck, 1992; Cilliers & Preiser, 2010; Guntzburger & Pauchant, 2014; Leveson, 2004; Pauchant & Mitroff, 1992).

1.3.2. Content Analysis Findings

Table 4 indicates the number of articles for each identified couplings. More than half of the papers (73) adopt an anecdotal connection, either by referring to the code of ethics or the responsibility of the engineers while discussing risk management, or by mentioning safety or risk concerns in a broader discussion about engineering ethics. 37 articles present risk management as an ethical duty, a responsibility or a requirement. This is positive, but we argue that such statements run the risk of limiting the enhancement of risk management practices by not questioning their ethical limits. Finally, 25 articles propose tools or reflections to introduce ethical risk management in engineering education. This discussion is developed in the next section.

Table 5. Number of articles for each nature of coupling

	Main focus on risk management with coupling with ethics	Main focus on ethics with coupling with risk management	Total
Anecdotal or illustrative	**18**	**55**	**73**
Duty, responsibility or requirement	**0**	**37**	**37**
Ethical risk management	**2**	**23**	**25**

Articles Focusing on Risk Management in Engineering Education

For papers addressing mainly risk management issues, almost all articles fall into the first category, and only 2 articles out of 20 make a critical coupling with ethics. Among the 18 papers presenting an anecdotal coupling between risk management and ethics, 7 refer once or twice to professional code or ABET criteria and 6 evoke the responsibility of engineers. This illustrates that there is dissociation, in the larger part of our identified papers focusing on risk management, between the technical aspect of risk management practices and their ethical counterparts. Ethics seems to be perceived as a checkbox rather than the way to question these practices.

Nevertheless, there are two articles which present critical relationships between ethics and risk management. For Perrin and Laurent (2008), in their analysis of curricula concerning safety and loss prevention in chemical engineering offered in three French engineering schools, ethics is nothing less than the basis for the future of safety education. They relay the point made by Harris *et al.* (1996) that "engineering ethics is as much a part of what engineers know as factors of safety, testing procedures or ways to design for reliability, durability and economy" (Perrin & Laurent, 2008, p. 89). Moreover, they show Hill's model (2003) illustrating a safety ethic which "provides the opportunity to strive to a new level of attention to safety" (*Ibid.*, p. 89-90). Unfortunately, despite their important effort to integrate ethics into risk management education using this model or case studies with ethical dilemmas, they offer little reflections on the methods used for risk identification and evaluation. Of course, ethical reflections should be made once risks are identified and assessed in order to make a responsible decision, but what if these risks are misidentified or wrongly evaluated?

In the second article, Liu *et al.* (2014) also find, in their examination of risk management education in China, that ethical dimensions are as much part of professional competences than technical dimensions. The authors identify 31 key components of risk management regrouped in three categories: knowledge (16 components), skills (13) and attitudes (2), the latter includes ethics. However, the very large part of their list being reserved for technical or organizational dimensions echoes the very weak connection between ethics and risk management observed so far. Despite the authors' acknowledgement of the key role of ethics in risk management education along their research, they do not provide an ethical reasoning or inquiry for their other key components.

We agree that ethics is a key component of risk management education, but we argue that what is missing is how this dimension affects the technical components while, also missing, is a discussion on what are the implications for effective risk management. To us, there are essential considerations warranting further development.

Thus, these two articles make important conceptual links by insisting on the role of ethics for safety and risk management. They discuss the essential place of ethics courses in risk management education. Unfortunately, they still lack clear and practical insights on how ethics straighten risk management procedures, especially risk identification and evaluation, and evidence on the effect of ethics practices on the risk management process.

Articles Focusing on Ethics in Engineering Education

Among papers addressing ethics in engineering education, 55 make an anecdotal connection with risk management, while 37 consider safety and risk management as engineers' ethical duty or responsibility. In these papers, the connection is made roughly through three approaches: 1- safety as a canon in ethics codes, standards or educational criteria, 2- safety or risk issues as ethical dilemmas or values and 3- safety as topics covered in an ethics lecture or within educational material such as scenario, case study or software. This illustrates that public safety and risk management is clearly acknowledged as an ethical issue or imperative, as formally stated in engineering ethics codes since the mid-1970s (Barry & Ohland, 2009; Pantazidou & Nair, 1999; Russell & Stouffer, 2003). Furthermore, there is a general agreement throughout this literature about ethics reflections and formal training being efficient tools for increasing the awareness of risk and safety issues and assuring public safety, at least partially (e.g. Colby & Sullivan, 2008; Jonassen & Cho, 2011; Kiepas, 1997; Lau *et al.*, 2013; Loui, 2005; Sinha *et al.*, 2007).

Otherwise, 23 articles present a developed analysis of the link between ethics and risk management. These analyses are mainly articulated around 1- the detailed presentation of existing pedagogical content and approaches or the proposition of new ones, 2- reflections over curriculum or structural needs and 3- criticism of traditional approaches used for teaching ethics in engineering education.

In particular, Cooley *et al.* (1991), Passino (1998) and Voss (2013) present and analyze innovative pedagogical material addressing largely the issue of risk management and public safety. As well, van de Poel *et al.* (2001) present an ethics course at Delft University while raising questions about the responsibility of individual engineers, organizations and general public in safety design and acceptable risk. Rowden and Striebig (2004) propose a three-hour unit to be included in an ethics course, based on economic considerations and environmental ethics to promote sustainability of product design. Rich (2006) analyzes the role played by engineers and the engineering society (among other actors) in the case of the Austin Dam failure of 1911 and their lack of social responsibility in the design, construction and operation of the dam. Monk (2009) argues that drama and the use of plays enable addressing a wide range of human concerns. One play that he discusses does address specifically the issue of safety and ethical decisions under emergencies. Finally, Newberry (2010) presents a pedagogic case based on his analysis of the Katrina disaster and gives examples of many macro-ethical issues related to risk management.

Adopting a curriculum-based point of view, Gunn and Vesilind (1983) and Russell and Stouffer (2003) argue for a holistic engineering education which would integrate multidisciplinary non-technical approaches, for safer practices and enhanced considerations of fair distribution of benefits and burdens, social justice and sustainable development. West Jr. (1991) argues that including more experienced practitioners in the faculty staff would better develop professional responsibility and safety in civil engineering. Herkert (2003) proposes a shift in the present posture of professional engineering societies regarding product liability in order to reconnect them with their responsibility toward public safety and their role in discussion and education of the ethical dimension in engineering design. Finally, Hauser-Kastenberg *et al.* (2003) argue for a shift in the engineering culture from a linear and deterministic paradigm to a holistic and non-linear paradigm and that such shift would be suitable for developing a curriculum that satisfies ABET requirements.

Lastly, Harris Jr (2008) argues that preventive ethics is mostly based on negative rules which are not suitable for the commitment to public good. Instead, he recommends integrating virtue ethics in engineering ethics education to better develop professionalism. Herkert (2005) argues for a better incorporation of macro-ethics issues in engineering ethics research and education, reachable through the integration of engineering ethics and STS. While agreeing with this, Son (2008) proposes that a macro-approach in engineering ethics has its own limitations in terms of the social impacts of technologies, and that the inclusion of a philosophy of technology in engineering education would help overcome these limits. Bucciarelli (2008) and Conlon and Zandvoort (2011), relaying the well-known analysis of the Challenger disaster made by Vaughan (1997), criticize the individualistic approach traditionally used in the teaching of engineering ethics and urge considering the complex organizational, social and historical context for a better assurance of public safety.

For Conlon and Zandvoort (2011), the integration of STS to engineering ethics would also help in this matter, while it may be insufficient for Bucciarelli (2008) who calls for a deep renewal of how we see engineering education. Furthermore, Mitcham (2009) argues in favour of considering social and historical differences of conceptions of public safety, health and welfare, such relativism having direct impacts on the corresponding responsibility of engineers. Conversely, Doing (2012) cautions about potential deviances of considering technical facts as contingent of social and organizational practices, arguing that such an approach may deflect both organizational and individual accountability. Also, Chang and Wang (2011) propose the use of Eckensberger's model (2003) for an ethical risk management based on cross-cultural education and critical thinking. Finally, using an empirical approach, Balakrishnan *et al.* (2013) suggest that socio-ethical education in the field of nanotechnology may eventually be ineffective to enhance awareness of risk and safety and propose several strategies to increase the efficiency of such training.

1.4. THE NEED TO DEVELOP ETHICAL RISK MANAGEMENT IN ENGINEERING EDUCATION

The small number of papers seriously considering ethics while focusing on risk management education is striking. However, we argue that such considerations are essential to overcome the ethical limits of risk management methods used in engineering. As presented above, some relevant articles from the education literature focusing on ethics give interesting and important bases to develop ethical risk management in engineering education.

The complex analyses of industrial crises such as Bhopal (see Shrivastava, 1987), Challenger (see Vaughan, 1997), the Nestucca Oil Spill (see Deschamps *et al.*, 1997) or Fukushima (see Guntzburger & Pauchant, 2014) clearly illustrate the need to develop more complex approaches to teach risk management and ethics in engineering, as proposed by Hauser-Kastenberg *et al.* (2003), Bucciarelli (2008) or Conlon and Zandvoort (2011). Most of the traditional scenarios used to teach risk management or ethics do not yet present such level of complexity. Furthermore, considering that engineers, because of their training, may eventually neglect or depreciate multiple dimensions (emotional, social, etc.), perspectives or approaches (Downey, 2005; O'Brien *et al.*, 2003; Richter & Paretti, 2009; Roeser, 2012), multidisciplinary training needs indeed to be developed in the engineering curriculum, as argued by Gunn and Vesilind (1983) and Russell and Stouffer (2003).

However, despite these positive elements, we argue that several dimensions are still insufficiently discussed in the engineering education literature. In particular, most of the analyzed articles, with very few exceptions, are centred on decision-making. It is, of course, essential to develop ethical reflections over decision-making in risk management. But it is only a part of the entire process of risk management. Equivalent reflections over methods and approaches used for risk identification and risk evaluation have to be developed further, particularly regarding the limits, when considering complex systems, of the probabilistic and decomposition approaches and uncertainty analyses. We believe that these limits identified and analyzed elsewhere in the risk management literature (see, for example, Aven & Zio, 2011; Leveson, 2004; Leveson *et al.*, 2009), call for more ethical questioning when teaching probabilistic approaches for risk management in engineering. The reflections about adopting a holistic and non-linear paradigm in engineering presented above will help in this matter, and they should be more explicitly applied while teaching risk management. The Ethics of Complexity (see, for example, Cilliers & Preiser, 2010; Woermann, 2013) and reflections on acceptable evidences (see Mayo & Hollander, 1991) may also eventually offer opportunities to address these limits.

As mentioned previously, some authors address the need for taking into account more complex situations or contexts when teaching ethics to engineers. Such contexts must certainly include different systems of values. We argue that more studies such as those proposed by Chang and Wang (2011) on national values and Bucciarelli (2008) on organizational values are necessary to address adequately the effect of different systems of values on risk management in engineering education. Added to value systems, Conlon and Zandvoort (2011) address the need for better student empowerment, so that they can understand and analyze organizational, social and political context and thus become more socially responsible. Moreover, it has been suggested elsewhere in the literature that different ethical perspectives affect decisions regarding risks (see Ersdal & Aven, 2008). None of the literature analyzed here has explicitly addressed this question. We believe that this issue should be further integrated in risk management and ethics education.

Also, all papers analyzed here have considered teaching ethics or risk management in a safe and quiet environment – the classroom – with no time pressure except the teaching period. Unfortunately, many situations of risk management appear during emergencies, in potentially life-threatening environments where the time pressure is extreme and critical. We believe that reflections on how emergencies may affect ethical decision-making and risk management should be further integrated in engineering education. As proposed by Monk (2009), drama and plays may be efficient pedagogic tools to address this issue.

Finally, as discussed by Hauser-Kastenberg *et al.* (2003), engineering is often based on a deterministic and linear paradigm. Therefore, engineering education might induce specific biases because of this paradigm, which may directly influence the perception of the concept of risk, and the methods to address it. These biases are in addition to the heuristic biases already identified in the literature for directly influencing risk assessment (see, for example, Leveson, 2015). Further research on how engineering education itself affects risk management approaches in engineering is still necessary to assess these biases and to propose efficient approaches to reduce them.

We believe that addressing these points in engineering education is essential to develop safer engineering practices and improve systems' safety. Although not focusing directly on education issues, several articles that were analyzed do address themselves to the engineering education community. This is essential to promote change in the profession.

We have restricted our analysis to published papers in peer reviewed journals specialized in engineering or ethics education. Our inclusion criteria, especially regarding journals having "ethics" in their title, constitute one of the main limitations of our study. Indeed, as discussed in some articles identified, the contribution of the STS community to the question raised in this review is particularly relevant. Journals such as Science, Technology and Human Values or IEEE Technology and Society Magazine have published very relevant articles. We can consider as interesting examples the work of Lynch and Kline (2000) on the sociotechnical aspects of the engineering practice and ways to sensitize students about it, the work of Manion (2002) on a sustainable development-grounded philosophy of engineering and the need to integrate it in engineering education, and the ethical reflections of van Gorp and van de Poel (2001) on engineering design. Furthermore, many pedagogical approaches and materials are not necessarily the object of published papers. Analyses of unpublished course contents, MOOCs, or pedagogical books are necessary to refine, enrich and add nuance to our discussion.

1.5. CONCLUSION

We have proposed in this article a systematic review of the relation between ethics and risk management in the engineering education literature. As analyzed, risk management is mainly perceived as an ethical imperative, achieved by means of technical and rational approaches rarely questioned. Few papers propose an ethical reflection over these approaches by presenting pedagogical content and approaches, and few analyze the curriculum or criticize traditional approaches used for teaching ethics and risk management in engineering education. More often than not, ethics is the prerogative of decision-making, without the methods used for risk identification and evaluation being questioned. Based on this review, we believe that there is an important need for adopting a complex, systemic and multidisciplinary approach to bring risk management a step further in engineering education. A more engaged relationship between risk management and ethics has also to be further integrated in engineering education if we wish to promote the necessary change within the profession toward more socially and environmentally responsible practices.

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Appendix

Table 6. References of papers focusing on risk management issues and coupling ethical concepts

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Table 7. References of papers focusing on ethics issues and coupling risk management concepts

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CHAPTER 2.
EMPOWERING ENGINEERING STUDENTS IN ETHICAL RISK MANAGEMENT (ARTICLE 2)

Article presentation

The previous chapter has provided some preliminary answers to the first general research question by analyzing the nature of the relation between ethics and risk management in the engineering education literature. Although some articles give interesting and important bases to develop ethical risk management in engineering education, it has been suggested that this relation is mostly of deontological nature, considering risk management as a moral obligation without, however, questioning its ethical limitations. This review, therefore, suggests that the capacity of empowerment of engineering education to approach risk management ethically may be limited. Moreover, it has also been observed that the question whether engineering education might induce biases in risk perspectives is not addressed in the analyzed literature.

Therefore, this article, submitted to *Engineering Studies*, proposes to fill this gap by presenting the analysis of the influence of academic engineering education over perspectives on several ethical aspects of risk management. Moreover, the capacity of empowerment of engineering education, assessed through the concept of self-efficacy, is also evaluated and analyzed. Data have been gathered using an online questionnaire answered by 200 engineering students.

Anticipating that this capacity might be limited, as suggested by the review, this article also presents an innovative pedagogical approach, based on ethical pluralism applied to risk management and active learning methodologies. This approach, operationalized through workshops, has been tested with 34 last-year engineering students. Its relevancy and efficiency to enhance educational empowerment has been evaluated using both surveys and group interviews.

Abstract

Engineers are often portrayed as unemotional calculators and technical problem solvers, suffering from disciplinary ethnocentrism. These characteristics might have influenced the methods used in engineering for risk management, which have been regularly criticized as ethically limited, especially regarding complexity, cooperation and emotions. The purpose of our study is to assess if engineering education influences these limitations. Our results, based on a questionnaire answered by 200 engineering students, challenge the existing literature and illustrate the necessity to change the stereotypical portrait of the engineer. Also, they highlight the need to improve engineering education. Indeed, using the concept of self-efficacy, we suggest that the present engineering education fails to empower engineers to engage in ethical risk management. We therefore propose an active-learning 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.

2.1. 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. The AZF chemical factory (2001) and the Texas city refinery (2005) explosions, the blowout of the Deepwater Horizon platform (2010), the Fukushima Daiichi nuclear disaster (2011), the Lac-Mégantic rail disaster (2013), the Bento Rodrigues dam disaster (2015) or the Tongi factory boiler blast (2016) are recent and edifying reminders of the potential dark side of our industrial activities.

Several studies have shown the complexity and the profound ethical dimension of industrial disasters (see, for example, Coeckelbergh, 2012; Deschamps *et al.*, 1997; Guntzburger & Pauchant, 2014; Shrivastava, 1987; Vaughan, 1997). 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. Cilliers & Preiser, 2010a; Guntzburger & Pauchant, 2014; Leveson, 2011), the necessity for participative risk identification and assessment (e. g. Cotton, 2009; Herkert, 1994; Renn, 1999), as well as the role of emotions (e. g. Roeser, 2010).

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 (Guntzburger *et al.*, 2015).

This issue of fragmentation for the engineering profession is well identified in the literature. For Richter and Paretti (2009) for example, the profession suffers from disciplinary ethnocentrism[20]. 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, strengthen 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 (2005), 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.

This question of interdisciplinarity in engineering education has been the object of a special issue in *Engineering Studies.*[21] This issue has offered reflections on the place of humanities and social sciences in engineering education based on the proposal of Bucciarelli and Drew (2015) for Liberal Studies in Engineering. Such proposition addresses directly the question of fragmentation as well as the need for engineers to realize the limit of their knowledge and to interact with other experts (Klein, 2015). It also highlights the difficulties to integrate humanities and social sciences in engineering education programs (Jackson, 2015).

The interdisciplinarity in regards to risk management has also been addressed in another special issue in *Engineering Studies.*[22] This issue has regrouped several articles analysing how the engineering profession shapes and is shaped by modern industrial crisis. In particular, Knowles (2014) has given a historical perceptive of the coevolution of disasters and engineering practice in the U.S. and has presented Disaster-STS (science and

[20] 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.
[21] Vol. 7, Nos.2-3, 2015.
[22] Vol. 6, No 3, 2014.

technology studies), a field for social science, humanities and engineering to meet regarding risk management.

Our study aims to offer a contribution in both these fields by answering three research questions: 1- To what extent engineering education influences perspectives on industrial risks and methods for managing them? 2- To what extent the present engineering education empowers students to engage in ethical risk management? And 3- How to promote, through humanities and social sciences, an ethical approach to risk management in engineering? We believe that these questions are of critical importance as the nexus between risk management and ethics is clearly underdeveloped in engineering education (Guntzburger *et al.*, 2016).

2.2. ETHICAL RISK MANAGEMENT, SELF-EFFICACY AND EMPOWERMENT

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, various authors have contributed to the development of ethical approaches to risk management and our study is based on the work of some of them, as presented in the next section. 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. These ethics are succinctly presented hereafter.

2.2.1. The ethics of complexity

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 (Leveson, 2011). 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 (Harvey & Stanton, 2014). They are at the base of the complexity science which consider 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[23].

These uncertainties and ambiguities necessarily bring a moral dimension in risk management (Sollie, 2007) that we address through the *ethics of complexity* developed mainly by Cillier (see Cilliers & Preiser, 2010a). 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 without an acceptance of uncertainties and responsibility, can eventually lead to inaction (van Asselt & Vos, 2006). Indeed, as Cilliers and Preiser (2010b, p. 271) 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."[24]

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 (Cilliers & Preiser, 2010b). Such a commitment is, for example, certainly reachable through dialogue.

2.2.2. The ethics of dialogue

Such an ethics 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

[23] See, for exemple, Weick (1995, pp. 91-99) for a analysis of the difference between uncertainties and ambiguities.
[24] This may raise questions about action during emergencies, which fall, however, beyond the scope of this paper.

basic assumptions on a matter. The work of Senge (1990) and Bohm (1996) are, among others, at the base of its development in organizations.

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 (Stern & Fineberg, 1996). Such a deliberative approach is also valuable for risk identification and communication, as the public may have a specific knowledge that experts have not (Checker, 2007), or inversely, that can be distorted by social amplification (Kasperson *et al.*, 1988). As argued by Renn (1999, p. 3049), 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 (Herkert, 1994). Indeed, 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" (Roeser, 2010, p. xxiii). Therefore, emotions are necessary to ensure ethical risk management.

2.2.3. The ethics of moral emotions

This ethics finds its modern roots in the work of the moral philosopher Adam Smith (see Smith, 2006). More recently, the Nobel prize-winning economist Amartya Sen and the philosopher Martha C. Nussbaum have largely contributed to the development of ethical theories based on emotions (see Nussbaum, 2001; Sen, 2011). The three philosophers have argued that rational thinking actually encompasses emotional reflections, and that they are essential for moral judgements.

In the field of risk management, Slovic has largely contributed to highlight the importance of taking into account public's perceptions and considering the interaction of reason and emotion (see Slovic, 2000). As well, Roeser (2012a) 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" (2012a, p. 103). Finally, Kastenberg (2014), with the concept of moral emoting, has argued that intuitive and emotional reactions, which are most of the time unconscious, precedes and structures reason and logic. For the author, emotions are essential to concretely engage in ethical behavior by conditioning our motivation of being so.

Although other ethics theories or traditions, such as the virtue ethics or the ethics of care are important in risk management (see Roeser *et al.*, 2012), 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.

2.2.4. Empowerment and self-efficacy

Conlon and Zandvoort (2011) 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 (1990). 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 Bandura, 1977, 1993). The concept of self-efficacy has to be differentiated from self-esteem. Indeed, self-esteem reflects on an affective evaluation on the self when engaging in a particular activity whereas self-efficacy is a judgment of the capability of engaging in a particular activity, regardless of the sentiment (Parker, 1998). 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 active-learning method to promote an ethical approach to risk management in engineering.

2.3. METHODOLOGY AND SAMPLE CHARACTERISTICS

2.3.1. Influence and empowerment of engineering education

To assess the influence of engineering education toward conceptions in risk management, an online questionnaire was constructed and validated by pre-testing. All first- and final-year bachelor students from a major Canadian engineering school were contacted through email and were asked to rate on a 5-point Likert scale their agreement (from 1- Totally disagree to 5- Totally agree) to randomly presented statements regarding risk management. These statements were derived mostly from the literature presented before. Several statements regarding deontology have also been included to take into account the key role played by codes of deontology as the perceived symbolic bridge between ethics and risk management in the literature (Guntzburger *et al.*, 2016). The final list of these statements is presented in Table 11.

As well, students were asked to rate their agreement to 4 different basic assumptions on the nature of risk assessment, presented in Table 8 and based on the classification made by Renn (1992): engineering (risk as statistical calculation), economic (profit-cost analysis), psychological (risk as subjective construct) and constructivist (risk as socio-cultural construct).

Table 8. Basic assumptions relative to four different conceptions of the nature of risk assessment.

Engineering	1. Statistical calculation based on the probability and severity of undesirable consequences ensure an objective and universal risk assessment.
Economic	2. Industrial risks of a project must only be assessed by comparison of the potential earnings of the project
Psychological	3. Industrial risk assessment is necessarily subjective as every individual has its own conception of risk.
Constructivist	4. The socio-cultural context structures industrial risk assessment.

For both statements and basic assumptions, an analysis of variance (ANOVA) using STATA analysis software as been conducted to test the level of significance of the observed differences of ratings.

As introduced before, the concept of self-efficacy was used in this study as a proxy for empowerment. May and collaborators (2014) 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 presented in Table 9 was developed based on their work to assess ethical risk management self-efficacy. Students 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.

Table 9. 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.

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 10 presents the demographic characteristics of the respondents.

Table 10. Demographic characteristics of the respondents (N = 200)

	1st year			***4th year***		
Engineering Program	Women	Men	*Total*	Women	Men	*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***

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 relitively 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.

2.3.2. 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 Felder *et al.*, 2000; Prince, 2004). 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.

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 (Macdonald, 2012). Students were invited to work in small groups of three to fours 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 Hetherington, 2013). More specifically in the engineering education field, Davis and Wilcock (2003) 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 Guntzburger & Pauchant, 2014). Each team of students was asked to identified 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" (Seiler *et al.*, 2011, p. 219).

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 Checker, 2007). 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's 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 (2012a), 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 Ivanaj *et al.*, 2014; Shrivastava, 2010). As well, according to Cazeaux (2000, p. xiii) cited in Ivanaj *et al.* (2014, p. 28), "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.* (2014) 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 discussion followed the realization of the metaphor.

2.4. RESULTS AND DISCUSSION

2.4.1. Influence and empowerment of engineering education

Originally, 25 statements were created to assess the influence of engineering education on dimensions potentially influencing or limiting in risk, including the role of codes of deontology. A principal component analysis (PCA) coupled with a promax rotation allowed us to regroup these statements in four factors, as presented in Table 11. Following Beavers and collaborators' recommendations, we retained only items with loading superior to 0.4, therefore dropping 4 items (see Beavers *et al.*, 2013). Three of the four factors show a satisfying internal consistency with a Cronbach's alpha (α) value of 0.70 or above. More caution has to be taken in interpreting the factor "Determinism" as a consistent construct for its α value is 0.60. However, such a value may be still considered significant as this construct is still under development, but further research is required (Hair *et al.*, 1998)..

Table 11. Results of PCA of Statements relative to risk management

	Emotions (α = 0.79)	Reductionism (α = 0.70)	Determinism (α = 0.60)	Deontology (α = 0.70)
1. Emotions play a key role in industrial risk management.	0.73			
2. Emotions are as relevant as scientific methods for industrial risk management.	0.68			
3. Part of the risk management process in engineering should be based on emotional concerns toward industrial risks.	0.72			
4. In industrial risk management, emotions are a source of ethical reflections.	0.71			
5. It is important to be aware of our own emotions in industrial risk management.	0.82			
6. The opinion of the public is not relevant in industrial risk management.		0.57		
7. The opinion of non technical experts (sociologists, psychologists, ethnologists, etc.) is not relevant in industrial risk management.		0.63		
8. In industrial risk management, it is useless to consider public opinion.		0.57		
9. Political decisions, natural environment, social context or culture are not source of industrial risks.		0.69		
10. Industrial risks evaluation must not consider political, environmental, social and cultural context.		0.67		
11. Industrial risks evaluation must be based on the decomposition and modelling of the analysed system.			0.50	
12. It is always possible to identify industrial risks through system modelling and decomposition.			0.58	
13. It is always possible to find the source of an industrial risks by analysing the causes and consequences of this risk.			0.55	
14. It is possible to objectively calculate positive and negative consequences of every decision relative to industrial risks.			0.61	
15. All industrial risks emerge from technical aspects of a system.			0.45	
16. It is possible to totally eliminate industrial risks using technical devices.			0.49	
17. Strengthening the code is necessary in the event of wrong industrial risk management.				0.46
18. Code of ethics is a reference in industrial risk management.				0.69
19. Decision making in risk management must be based on the code of ethics.				0.78
20. The use of the code of ethics is essential in industrial risk management.				0.84
21. The code of ethics ensures an ethical industrial risk management.				0.49
Percentage of variance explained	*11.9*	*10.1*	*10.0*	*9.0*

Note: loadings < .40 are not presented here

Before looking at the influence of the engineering training by comparative analysis, it is relevant to look at the first-year students' results only, to assess if they show a particular profile. Indeed, students usually select a professional training according to their preference. The danger of fragmentation, discussed before, is therefore both influenced by program selection and training (Wörsdörfer, 2014).

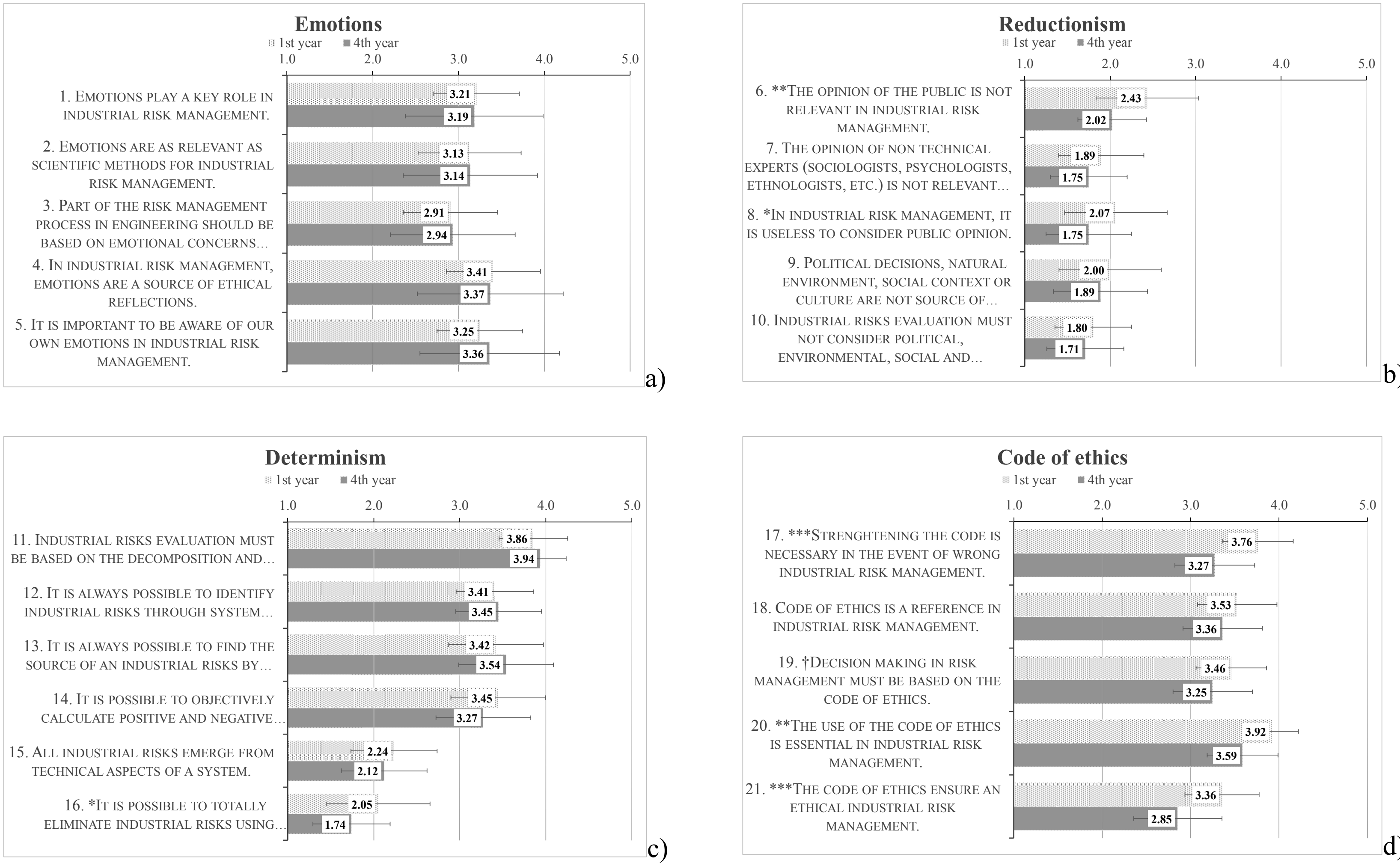

Figure 4. Rating of agreement to items composing 4 different dimensions: Emotions (a), Reductionism (b), Determinism (c) and Code of ethics (d), potentially influencing risk management for the 1st and 4th year students (N=200, *** p<0.001, ** p<0.01, * p<0.05, † p<0.1)

Professional program selection. Interestingly, looking at Figure 4a), first-year students tend to agree that emotions are a source of ethical reflections in risk management (item 4) and they generally consider that emotions are important in risk management (average item's rating significantly superior to the midpoint 3: item 1; $p = 0.042$ and item 5; $p = 0.000$). On the other hand, they are having more difficulties settling the question if emotions are as important as rational approaches (item 2; $p = 0.11$). This wavering is also exemplified by their lack of opinion toward the place of emotional concerns (item 3; $p = 0.35$).

Looking now at quadrant b), they seem to clearly value inputs from the public (items 6 and 8) as well as from other, non-technical, experts (item 7) and acknowledge the necessity to consider the political, cultural, social and environmental context in risk management (items 9 and 10). This is consistent, when looking at quadrant c), with their acknowledgment of the importance of non-technical dimensions in risk management and thus, the limited efficiency of purely technical approaches (item 15 and 16). Still, they tend to agree, but not too strongly, with the usefulness of decomposition and modelling in risk management (items 11, 12, 13 and 14).

Finally, when looking at quadrant d), they seem to acknowledge the relevance of codes of ethics in risk management by showing a relatively positive appreciation of its usefulness (quadrant d).

Thus, students engaging an engineering training tend to favour a deterministic approach to risk management based on decomposition and modelling, which is consistent with the traditional engineering mindset. Also, they clearly value emotions but seem not being able to reconciling them with rationality and recognizing them as a valid source of concern. Finally, they acknowledge the necessity to consider the complexity of the context as well as the public's and non-technical experts' opinions. This is consistent with their assumption regarding the nature of risk assessment as illustrated in Figure 5. Indeed, they are more in agreement with both a constructivist and an engineering nature of risk assessment while significantly rejecting an economic definition ($p = 0.0005$).

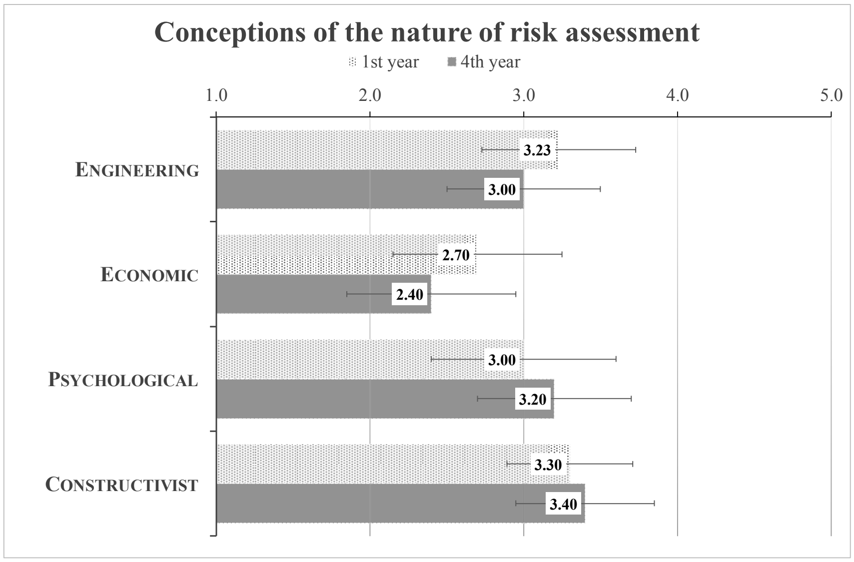

Figure 5. Rating of agreement to four different conceptions of the nature of risk assessment for the 1st and 4th year students (N=200, *** p<0.001, ** p<0.01, * p<0.05, † p<0.1)

Professional training influence. Looking back at Figure 4, one can see that there is a significant difference of answers between first- and last-year students to 7 items over 21. In contradiction with a large part of the present literature, this difference is not one of narrowing but of opening, particularly regarding public's opinion (items 6 and 8). While being as much in agreement with the necessity to consider the complexity of the context that first-year students and still also favoring modelling and decomposition approaches, they are more aware of the limited efficiency of technical devices in risk management.

This general evolution is also reflected in their ratings of assumption of the nature of risk assessment as they are significantly more in agreement with a constructivist definition that an engineer one (p = 0.0031).

Also, while not rejecting the use of a code of ethics in risk management, they question more its relevance as an efficient tool than do first-year students (items 17, 19, 20 and 21). This result is particularly important, as codes of ethics, through the mention of the first fundamental canon (see, for example, NSPE, 2015), is often perceived as the major – if not the unique – link between ethics and risk management (Guntzburger *et al.*, 2016). If it is essential for engineers' societies to stress on the importance of safety as a fundamental obligation of any engineer, it is, however, also essential to promote training for the students to do so correctly by going beyond wishful thinking.

To sum up, engineering students tend to value determinism, which is consistent with the general problem solving approach in engineering. Therefore, they might naturally answer risks through modelling, decomposition and mathematical calculations, with the limits associated especially in complex socio-technical contexts. However, this mindset seems not to be reinforced during their curriculum. On the contrary, they are positively influenced to better consider the context and others' opinions. This positive observation can surely be attributed to years of efforts of integration and development of team-work and multidisciplinary within the engineering curriculum, as well as recent and highly mediatised public mobilizations against major technical projects such as the TransCanada pipeline development both in Canada and the U.S..

Finally, even if their training seems not to have a significant influence on the matter, fourth-year engineering students acknowledge the importance of emotions. Like their first-year fellows, this acknowledgement is actually ambivalent and might explain why it is moderate according to the survey. This observation was, however, not captured by the questionnaire but through group discussions during workshops. This highlights one limit of quantitative analysis. Narratives are also important to make sense of the data. Some of the students' interventions are therefore worth presenting now. For example, here are some elements which emerged during a discussion:

> Student 1: "Today, we know the importance of the emotional intelligence. We need to recognize and understand our own emotions, and take decisions accordingly without disregarding them";
>
> Student 2: "We should not be overwhelmed by our emotions, because it harms, it disturbs our judgement";
>
> Student 3: "Well, it depends on the situation. Absolute rationality is not possible anyway";
>
> Student 4: "If an emotion emerges, there is a reason. We need to understand this reason to go further";

> Student 5: "In engineering, we work systematically. Adding emotions, it's adding a personal variability".

Other elements having emerged during another discussion:

> Student 1: "To know to manage our emotions, it is not being unemotional, it is to know what to do with them";
>
> Student 2: "I agree, decision-making cannot ignore emotions, they are essential";
>
> Student 3: "But it is clearly not the prevailing message in engineering, you have to be objective, emotions should not affect our judgment".

These are illustration of a ambivalent, yet quite unanimous, perception of the emotional dimension. Students acknowledge the necessity to consider emotions in decision-making while still having trouble reconciling emotion and rationality, mostly because of the potential negative effect of emotional overwhelming on decision-making. However, while they generally agree that 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 (2001) 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 (1992) cited in Roeser (2012b, p. 1035)). This might explain why instantaneous judgements, which rely more on an emotional dynamic than an analytical one, is often perceived as the good ones. 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 12. Spearman' correlation coefficients between dimension potentially influencing risk management and nature of risk assessment

	1	2	3	4	5	6	7
Dimensions potentially influencing risk management							
Emotions (1)							
Reductionism (2)	-0.05						
Determinism (3)	-0.06	**0.19** **					
Code of ethics (4)	-0.12	0.11	**0.33** ***				
Nature of risk assessment							
Engineering (5)	-0.10	**0.16** *	**0.33** ***	**0.37** ***			
Economic (6)	0.05	**0.20** **	0.07	0.10	0.00		
Psychological (7)	**0.26** ***	0.01	-0.03	-0.12	0.06	0.05	
Constructivist (8)	**0.28** ***	-0.08	-0.16	-0.03	-0.09	0.00	**0.17** *

*Notes: *** p<0.001, ** p<0.01, * p<0.05*

Finally, Table 12 regroups Spearman's correlation coefficients between statements our dimensions potentially influencing risk management and the nature of risk assessment for our entire sample of 200 students. Even if several observed correlations are weak, some are very significant. For example, students showing an agreement with a constructivist or psychological perspective will tend to lightly, but significantly, also be in agreement with statements relative to the importance of emotions. Similarly, students more in agreement with a reductionist or deterministic approach to risk management will tend to adopt also engineering basic assumptions regarding risk assessment. Furthermore, one can observe a significant correlation between the deterministic and reductionist dimensions. This echoes the relation discussed before between the influence of the complex context and the limits of technical measures in risk management. The significant correlation presents between the deterministic and deontology dimensions is, however, much less easy to interpret.

It is, of course, very difficult to attribute any causality between basic assumptions regarding the nature of risk and agreement with dimensions relative to risk management. However, it may suggest a relative consistency. Further studies should be done to deepen this aspect.

To conclude this part, it is important to note that for many of the items of our factors, the ratings are in a sort of neither-agree-nor-disagree spot. It suggests that engineering education does not allow for strong opinions regarding risk management, which illustrate a lack of training regarding this fundamental responsibility. This finding is consistent with what can be found in the engineering education literature (see Guntzburger *et al.*, 2016). Without appropriate training, students are therefore limited in their capacity to question traditional approaches. They might know what would certainly help ethical risk management, but not how to deal with it. A lack of empowerment should therefore be expected.

Ethical risk management empowerment. Figure 6 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 (2014) in their study.

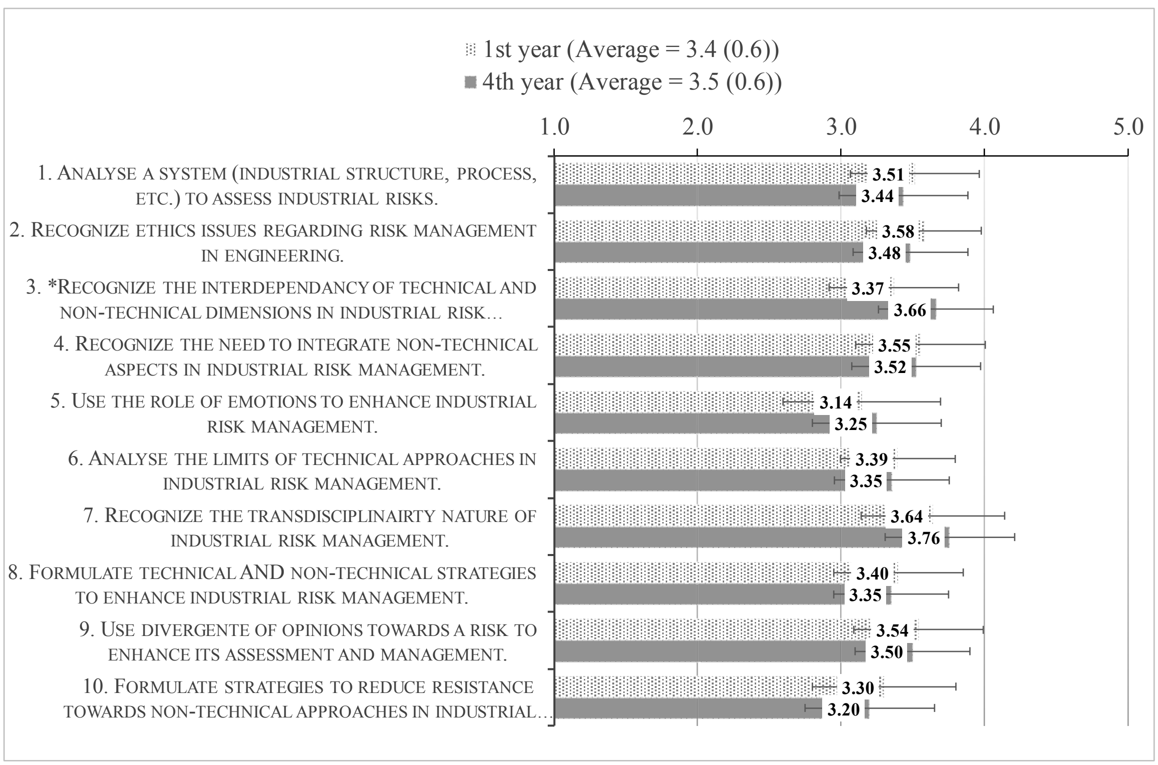

Figure 6. Self-efficacy scale for ethical risk management for the first- and last-year students (N= 200, alpha = 0.87, * p<0.05)

As expected, this scale suggests that globally, engineering education induces no significant change in the self-efficacy for ethical risk management, 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 the opening to non-technical dimensions discussed previously. Globally, students are moderately confident in their capacity to engage in ethical risk management.

As discussed before, engineering education seems not to reinforce a narrowness or fragmentation regarding ethical risk management practices. Yet, it does not empower students to engage in them either. 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 potential less ethical peer practices or organizational pressures, such as speed of decision or cost reducing.

Notwithstanding this, we believe that all these results shed a new light on engineering education. We argue that most of the present literature has a pessimistic point of view about engineers or engineering education. The effort to integrate and enhance team work, sustainable development, social responsibility, ethics, emotional intelligence or creativity in the engineering education seems to be fruitful. It appears to limit engineers to be the unemotional, ethnocentric calculators they are often criticized to be. They are open to reflexivity about their actions and their identity as engineers.

Unfortunately, their training seems not to prepare them adequately to transform these reflections in concrete ethical actions. To help in this matter, we therefore propose an active-learning method inspired by the ethics of complexity, dialogue and moral emotions.

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

Figure 7 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 engage in the learning.

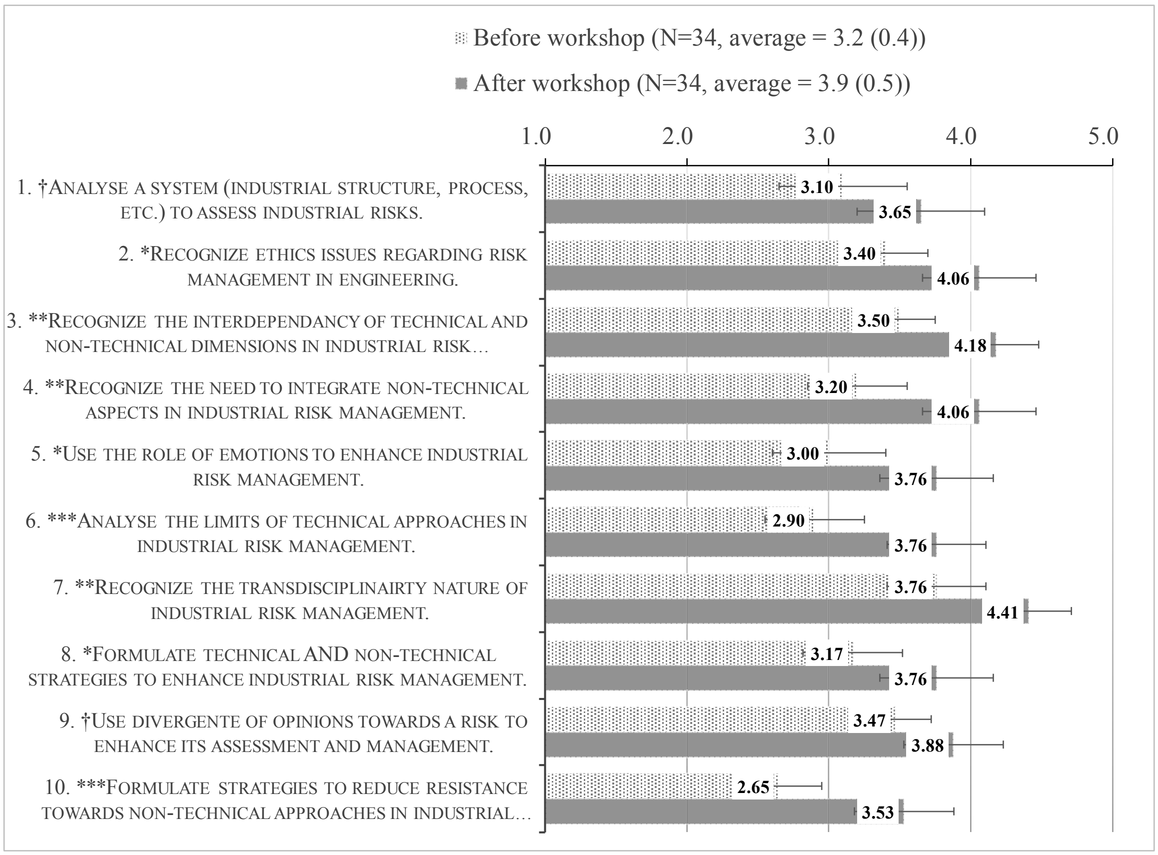

Figure 7. Self-efficacy scale for ethical risk management for chemical engineering students, before and after workshops (N=34, alpha = 0.91, *** p<0.001, ** p<0.01, * p<0.05, † p<0.1)

Table 13. Examples of rich pictures from the aesthetic workshop on emotional reflection

Also, Table 13 presents two examples of "rich pictures" made during the aesthetic workshop. It is not an easy task to finely analyse these creations, but the "I am you" in the first picture along with all the right side of the second one illustrate pretty well the notions of empathy and compassion that have emerged during this workshop. This echoes the positive evolution of item 5 in the ethical risk management self-efficacy scale presented in Figure 7. Also, this result reinforces the idea discussed before that art-based creative reflections have the ability to trigger reflections on positive moral emotions.

Table 14. Usefulness, relevance of pedagogical approaches, comfort and relevance of developing a course for each workshop's theme (N=34).

	Complexity		Collaboration		Emotions	
	Mean	SD	Mean	SD	Mean	SD
Usefulness	4.96	(0.2)	4.89	(0.3)	4.70	(0.5)
Relevance of pedagogical approaches (case, role-play and aesthetic)	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 14 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 reflections 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".

These statements echo the discussion made in the previous section. 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.

2.5. 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 are required to address these issues.

Three other biases might also limit the generalization or the interpretation of these results. First, this study was not longitudinal. Last-year students are not the same individuals that first-year students four years later. Maybe they are engaged in activities that nuance the influence of their training. However, they followed a relative stable engineering training, and it was not correlated with a straightening of the fragmentation of their perspectives toward an ethical risk management. Second, answers of the questionnaire and participations to the workshops were on a voluntary basis. Therefore, it is more than likely that only students already concerned by risk management have participated in this study and that these students have a less narrow approach to risk management than others do. Finally, some statements used are subject sensitive, particularly for public's and non-technical expert's opinions. Participative students might have guessed that considering public opinion was a more ethical answer. But this is precisely the whole point of this study, to assess if they are able to perceive what a more ethical approach to risk management might be.

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 managements 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.

2.6. 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 Mitcham, 2014). 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. Focusing specifically on industrial risk management, our study suggests that such efforts are fruitful and that the stereotypical portrait of the engineers as an unemotional ethnocentric calculator needs to evolve along with their educational training.

Indeed, engineers seem not to be adequately prepared to engage and promote ethical risk management, which will 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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CHAPTER 3.

Professional Ethnocentrism and Ethical Risk Management Efficacy: The Mediating Role of Emotions Among Engineers (Article 3)

Article presentation

The first two articles have allowed to partially answer the research questions by focusing exclusively on the educational side. However, it was also intended to analyse to what extent current engineering practice empower engineers into an ethical approach of risk management. Indeed, one may question the relevance to address the issue of risk management only at the educational level, since students have only a limited knowledge of the industrial field. Although I rather disagree with this argument – point that I develop later in the general conclusion of this thesis – to analyze the influence of the professional practice indeed enriches this study and significantly contribute to its robustness, relevance and practical utility.

This article, submitted to *Safety Science*, offers an analysis of the relation between individual empowerment in an ethical approach of risk management, conceptualized through the notion of ethical risk management efficacy, professional ethnocentrism, a potential bias in safety engineering, and emotional openness in a risk management situation. Data have been gathered using a questionnaire answered by 178 professional engineers.

To the best of my knowledge, this is the first study addressing the question of safety in engineering using the notion of empowerment, and more specifically, the concept of self-efficacy. Adding the ethical dimension make therefore this article even more original.

Abstract

Professional ethnocentrism among engineers is an important issue for the development of an ethical risk management. Indeed, it may impede them to acknowledge and value the plurality of legitimate perspectives on risks which usually challenge their technical point of view. It is therefore crucial to understand what may influence such ethnocentrism. In this study, 178 professional engineers were asked through a questionnaire to rate their agreement on several statements regarding professional ethnocentrism and emotions, as well as their perceived confidence in their ability to achieve specific tasks promoting an ethical approach of risk management. Our results suggest that engineers with higher Ethical Risk Management Efficacy (ERME) are less subject to professional ethnocentrism, this relation being fully mediated by emotional openness. Multidisciplinary education is often suggested as a way to limit professional biases in engineering. While we agree on the benefits of such an approach, we argue that it should also extend its rationality by actively involving emotional reflections, as their development could support engineers transcending their technical perspective on risk. Being more sensitive to complex and ethical dimensions of safety, engineers would be more prone to engage in an interdisciplinary and deliberative approach of risk management. Finally, such training should specifically aim at enhancing their self-efficacy in ethical risk management to efficiently support such a project.

Keywords: multidisciplinary, public deliberation, risk management, ethical self-efficacy, emotional openness, safety engineering.

3.1. INTRODUCTION

The increasing complexity of engineering projects requires the collaboration of professionals from many different disciplines. Even truer when integrating these projects in sustainable development and corporate social responsibility dynamics, engineers have to acknowledge and value, now more than ever, both “hard-” and “soft-” science perspectives. Moreover, the social acceptability of risks has also become an important aspect of industrial developments. Several recent projects have caused serious debate and controversy, leading to major delays or even their cancellation, which may have been avoided if public concerns had been properly considered from the beginning. Examples include the Toronto power plant (2010) or the Energy East pipeline (2015) in Canada, the Dakota access pipeline in the U.S. (2016) (though it has been reactivated recently by executive order), or the new Nantes airport in France (2016).

These new considerations call for engineers engaged in risk management to not solely focus on the technical aspects of projects in order to be able to adequately address the complex and ethical dimensions of safety. Acknowledging the limits of the traditional curricula in sensitizing students to the valorization of multiple perspectives, several authors have suggested the use of multidisciplinary approaches in engineering education to address this issue (see, for example, Bucciarelli & Drew, 2015; Downey, 2005; Gunn & Vesilind, 1983; Mitcham, 2014; Richter & Paretti, 2009). Although very relevant, these suggestions are mostly grounded in an analytical-rational point of view, which usually neglect or discard emotions. However, an increasing body of literature acknowledges their importance in risk management, especially regarding the perception and acceptability of technological risks (see, for example, Roeser, 2006, 2012a; Sjöberg, 2007; Slovic, 2000). Emotions, particularly in engineering, are often perceived as a source of biases to rational thinking, which should be avoided for better objectivity. We argue on the contrary that emotions, even though they are not infallible, are legitimate sources of information to be considered in moral judgment (Nussbaum, 2001). They may allow engineers to be more aware of complex and ethical dimensions in risk management, and hence that they should be valorized in safety engineering (Roeser, 2006, 2012a).

Using the concept of self-efficacy, this paper aims to address empirically two issues: 1. To what extent does the self-perception of individual's abilities to ethically approach risk management influences professional ethnocentrism? And 2. What is the role of emotions in this relation?

The next section addresses how the acknowledgment and the valorization a plurality of legitimate risks perspectives may contribute to an ethical approach of risk management in engineering, and how professional ethnocentrism may then impede such an approach. Then we present how self-efficacy and emotional reflections applied to risk management may influence professional ethnocentrism, while exposing our research hypotheses. Next, the quantitative methodology used to verify those is explained. Finally, our results are presented and their implications discussed.

3.2. PROFESSIONAL ETHNOCENTRISM AND ETHICAL RISK MANAGEMENT

Engineers usually perceive risk management as a value-neutral, non-normative activity and consider risks as objective features of technologies or processes (MacLean, 2009; Wendling, 2014), technically quantifiable as the product of the probability of occurrence and the severity of consequences. However, science and engineering are not value free (Bucciarelli, 2008; Lekka-Kowalik, 2010; Vesilind & Gunn, 1998). Technological design and development are value-laden processes in which engineers are asked to consider their responsibility (Van Gorp & Grunwald, 2009). In particular – and usually in contradiction with positivist approaches – the whole process of risk management, from risk identification to data collection, communication, evaluation and to decision-making on risk acceptability, is deeply value-laden (Mayo & Hollander, 1991; Roeser *et al.*, 2012) and requires normative judgments (MacLean, 2009; van de Poel & Fahlquist, 2012).

Risk analysis expresses several faces, both because of the nature of risks themselves (may they be ecological, technological, sanitary, economical, etc., although the interleaving of these spheres makes the distinctions more and more blurry), and because of the diversity of possible definitions and approaches among scholars (Riesch, 2012). This has led to what Funtowicz and Ravetz (1993, p. 739) have called a "plurality of legitimate perspectives" on risks. This pluralism raises important ethical questions for risk analysis and management such as: what are the values and basic assumptions structuring each perspective? Considering this "plurality of legitimate perspectives", who can be deemed a risk expert and which of these perspectives are necessary and sufficient for sound and ethical decision-making regarding risks?

To address these questions, engineers should therefore challenge their perspective. Cooperation with non-technical scientists, especially social scientists, can help them identify the values and underlying assumptions related to their own perspective of risk management (Wendling, 2014). However, because engineers usually prefer a technical approach to risk management, it may be unnatural for them to integrate a constructivist perspective and to move their responsibility beyond the sole technical execution of risk management (Kermisch, 2012; Wendling, 2014). Indeed, while interdisciplinary and ethical competences are now required to be developed by engineering education (see ABET, 2015), valorizing a diversity of legitimate perspectives, especially if non-technical, does not seem to be the strong suit of engineers. Richter and Paretti (2009) have argued in their case study that engineering students, suffering from "disciplinary egocentrism" as they called it, usually "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" (p. 38). In line with their observation and inspired by their concept of disciplinary egocentrism, we define *Professional Ethnocentrism (PE)*[25] as the propensity for an engineer to mostly valorize perspectives from members of the engineering profession, neglecting other experts' opinion, but also laypeople's as well.

Indeed, as we have suggested in the introduction, public voices about risk perceptions and acceptability are gaining more leverage nowadays, especially since the rise of internet and social media. They are, however, usually perceived as misinformed, irrational and biased, and hence are not considered by scientists, such as engineers, engaging in a technical approach to risk management (Lidskog & Sundqvist, 2012). Such rejection however raises serious ethical questions such as prior consent to accepting risk, or justice and fairness in the distribution of risk (Beck, 1986; MacLean, 2012; Shrivastava, 1987). Numerous authors have therefore argued for the legitimacy, the seriousness and the richness of public perspectives on risks and for the necessity to integrate them in a deliberative process in order to promote an ethical approach to risk management (e.g. Checker, 2007; Cotton, 2009; Herkert, 1994; Slovic, 2000; Stern & Fineberg, 1996). Of course, it does not mean that the public is systematically right about risks, that their judgment cannot be distorted or manipulated by "alternative facts", and that their sole and only opinion should be considered. It does mean, however, that determining whether their opinion is legitimate or not is in itself an ethical debate that should be integrated in the risk management process.

[25] In our work, we have privileged the word ethnocentrism instead of egocentrism since we understand that engineers will judge – and eventually neglect – other perspectives relatively to their discipline's assumptions or values, which are at the group level not the individual (Campbell, 2009).

As argued by Van Gorp and Grunwald (2009), for whom deliberative democracy (Barber, 1984; Habermas, 1985) should serve as a normative framework for the responsibility of engineers in design processes, all these considerations certainly call for an interdisciplinary and deliberative approach of risk management in order to morally justify risk-imposing industrial activities (MacLean, 2012). The acknowledgement and the valorization of this diversity of value-laden perspectives from other disciplines and lay people, if efficiently put in practice, would allow for a mutual enrichment and a better consideration of the complexity of risk management and therefore contribute to an ethical approach of this practice. Professional ethnocentrism then, raises an important issue since it would specifically impede engineers to benefit from such enrichment and would therefore limit them in the development of an ethical approach of risk management. Understanding to what extent self-efficacy influence professional ethnocentrism would surely help address this issue.

3.3. SELF-EFFICACY IN RISK AND SAFETY MANAGEMENT

Self-efficacy, a major concept in behavioral science, is defined as an individual's perceived ability to successfully achieve a desired action which contains ambiguous, unpredictable and often stressful dimensions (Bandura, 1977, 1981). Individuals with a higher perception of their self-efficacy for a given action are likely to be more motivated and persistent in their engagement in such an action, and to set up for themselves higher standards of realization or outcome expectations (Bandura, 2001; Schunk, 1995). Self-efficacy is not a frozen characteristic of an individual, and is influenced, among other factors, by performance accomplishment, his own individual's or vicarious experiences, social persuasion or emotional arousal (Bandura, 1977).

Self-efficacy has been associated with safety and risk management particularly within the medical and public health fields, especially to investigate, with mitigated results, individual risk or health behaviors (see, for example, Clark & Dodge, 1999; Llewellyn *et al.*, 2008; Thompson *et al.*, 2009; Volkmann *et al.*, 2014; Wiener *et al.*, 2007). Self-efficacy has, furthermore, been used for health-based program evaluation (e.g. Delgadillo *et al.*, 2014; Glazebrook *et al.*, 2011; Leigh, 2008; Mahat *et al.*, 2016; Nishisaki *et al.*, 2007; Sol *et al.*, 2008), or safety performance assessment (e.g. Katz-Navon *et al.*, 2007).

The nexus between safety and self-efficacy is, of course, not unique to the medical and health fields. Several authors have analyzed, using self-efficacy-based concepts, industrial or occupational safety or risk management within specific industrial context such as the steel industry (Brown *et al.*, 2000), the agricultural (Blackman, 2012) or public sectors (Grau *et al.*, 2002), the coal mining (Chengcheng & Naiwen, 2010) or the air transport industry (Chen & Chen, 2014). Overall, these studies have suggested that individuals with a higher degree of self-efficacy will be more motivated, directly or indirectly, to engage in safety behaviors. Instead of targeting specific industries, other scholars have chosen to address specific safety issues and behaviors, such as the use of hearing protection (Arezes & Miguel, 2008), the reporting of near-miss accidents (Su, 2014), or safe driving (e.g. Huang & Ford, 2012; Newnam *et al.*, 2008; Okamura *et al.*, 2012; Victoir *et al.*, 2005; Weiss *et al.*, 2013) which is a major industrial safety issue, particularly in the Oil and Gas industry (Retzer *et al.*, 2013). These studies also suggest a significant positive relationship between self-efficacy and safety behaviors.

While these different studies address one of the major issues in engineering, i.e. safety, very few of them actually come from engineering scholars, or target engineers specifically. This is both surprising and not surprising. On the one hand, it is surprising for self-efficacy is actually well acknowledged in the engineering field, but mostly within educational studies. For example, identified papers address varied topics such as undergraduate students' perceptions of their capacities in academic achievements or specific skills (Alves *et al.*, 2016; Mamaril *et al.*, 2016), comparative gender studies (Concannon & Barrow, 2012) and analysis of confidence and feeling of inclusion for women students (Lourens, 2014; Marra *et al.*, 2009). Still using self-efficacy, other studies have presented the analysis of engineering design education (Carberry *et al.*, 2010), teaching capacity (Yoon Yoon *et al.*, 2014), instructional delivery strategies (Ponton *et al.*, 2001) or students' satisfaction (Micari & Pazos, 2016) and retention (Kinsey *et al.*, 2008) in their program. Finally, the influence of pre-collegial or general factors (Fantz *et al.*, 2011; Hutchison *et al.*, 2006), background characteristics (Santiago & Einarson, 1998) or year of entry in the program (Concannon & Barrow, 2009) on engineering academic achievements self-efficacy have also been studied.

On the other hand, it is not surprising that very few engineering scholars actually use self-efficacy concepts for safety studies, since traditional approaches to risk and safety management in engineering are presupposed to be more objective and technical than individual and psychological. While we agree that it is essential that scholars from different disciplines contribute to the study of industrial safety issues in an interdisciplinary manner, we believe that it is also important that engineers themselves integrate and value concepts from other scientific fields in order to challenge and enrich their own perspective of risks. Moreover, the diverse industrial safety studies presented before are usually focused on the worker or operator level, in their already developed technological environments and existing risks, and target safe behaviors. None of them focus on the individuals who develop these environments and have the responsibility for their safety.

Hence, in this study, we specifically target engineers and analyze to what extent their perceived confidence in their abilities to approach risk management more ethically influence their propensity to consider non-technical opinions in the risk management process. For this purpose and based on the definition of self-efficacy, we define *Ethical Risk-Management Efficacy* (ERME) as the individual's perceived confidence in his or her ability to achieve several tasks that, according to the development made in the previous section, are usually not associated with their technical perspective but contribute to the development of a more ethical approach of risk management. These tasks are presented later in Table 17.

Moreover, engineers, in their practice, will actually face a complex reality, with social, organizational and political dimensions (Bucciarelli, 2008), especially in risk management. Indeed, perhaps one of the most popular models for addressing industrial safety issues in several industrial domains is the model of James Reason (1990) (Larouzée & Guarnieri, 2015), which analyze organizations accidents using both technical and non-technical dimensions. Therefore, the technical perspective of engineers, by force of practice of risk management in organizations, may well be challenged as they surely are confronted to the pluralistic nature of risks and the relevance of non-technical dimensions, ethics issues or public opinions. Following the self-efficacy theory, we argue that these experiences will influence the individual’s self-efficacy (Bandura, 1977) and we thus propose our first research hypothesis:

H1: Engineers’ experience in risk management practice (frequency) positively and significantly influences their ethical risk-management efficacy (ERME);

Moreover, based on the self-efficacy theory, we suggest that engineers experiencing a weak confidence in their ability to face these non-technical dimensions may fall back on what they are familiar and comfortable with, i.e. the technical approach. Said differently, a low ERME may influence engineers to exhibit professional ethnocentrism. In line with this, we propose our second research hypothesis:

H2: Engineers with a higher ethical risk-management efficacy (ERME) will have a lesser propensity to professional ethnocentrism (PE);

3.4. THE PLACE OF EMOTIONS IN ETHICAL RISK MANAGEMENT

In a stereotypical fashion, engineering is often associated with the masculine image of the practical, analytical calculator for whom rationality is not compatible with emotions (Hatmaker, 2012). When considered at all in engineering, emotions are most often valorized as contributing to relational skills rather than to professional judgments in the engineering practice. Emotions are indeed often perceived as bias in rational thinking (Roeser, 2010). However, in many fields such as moral philosophy, psychology, ethology and behavioural studies to name just a few, it has been argued that emotions play an essential role in moral decision-making (e.g. de Waal *et al.*, 2009; Lerner *et al.*, 2015; Nussbaum, 2001; Smith, 2006 (1759)). In the last decades, neuroscience research has shed new light on cognition by showing the deep interconnections between emotional and rational processes in decision-making. With his study of brain-injured patients in the mid-90’s, Damasio found that the individuals who suffered from prefrontal cortex damages had a decrease in both rational thinking and emotional competencies and that some brain areas were involved in both processes (Damasio, 2005). This supported the theory that emotions are an essential aspect of rational judgment, an idea that has since been confirmed by other neuroscientific studies (e.g. Okon-Singer *et al.*, 2015; Pessoa, 2008; Phelps *et al.*, 2014).

Despite these scientific works, the still dominant analytical-rational approach in risk management in engineering is still lacking emotional considerations. This is problematic from an ethical point of view, as emotions may serve as legitimate moral references for risk acceptability (Roeser, 2006, 2010, 2012b). Once again, one has to be cautious here, as such statement could be an open door for legitimizing manipulations of emotions towards specific risks for political or economic purposes, for example. We argue, however, that emotions, just like analytical calculations, are not infallible, yet they certainly are valuable sources of information (Nussbaum, 2001) and of intuition (Haidt, 2001). Emotional and cognitive processes are thus part of a complex relationship involved in moral reasoning in general (Decety *et al.*, 2011) and in moral risks judgment in particular (Coeckelbergh, 2010).

Engineers, therefore, "should not be unemotional calculators; [...] they should work to cultivate their moral emotions and sensitivity, in order to be engaged in morally responsible engineering" (Roeser, 2012a, p. 103). By grounding individuals in the situation and revealing non-technical, although essential, dimensions of safety engineering, emotions have the potential to enhance sensitivity to complex and ethical. Therefore, we suggest that recognizing and valorizing the essential role of emotion in risk assessment and management is an important capacity of ethical engineers.

Besides, emotions are not stranger to the self-efficacy theory. According to Bandura (1977), emotional arousal – the feeling perceived by an individual when considering a situation – influence, through cognitive and judgmental processes, "the level and direction of motivational inducement to action" (Bandura, 1977, p. 199) and therefore, his or her perception of efficacy for this task. Conversely, self-efficacy also influences emotional reactions, such as that an individual with a higher perception of his or her capability to achieve a task is less prone to anxiety reactions for example (Bandura, 1977, 1981). Hence, several emotion-based variables, in particular emotional intelligence, have been used in some self-efficacy studies. For example, Gundlach *et al.* (2003) have proposed that emotional intelligence positively influence self-efficacy for it helps analyze and regulate emotional arousal. This proposition has since been empirically validated (see Mortan *et al.*, 2014; Sommaruga *et al.*, In press).

However, by defining in this study *Emotional Openness (EO)* as an acknowledgement and a consideration of the potential role of emotions in risk management, we do not consider EO as an antecedent of ERME but rather as an outcome. We argue that an engineer with higher perceived confidence in his or her ability to achieve specific tasks that challenge his technical perspective and contribute to an ethical approach of risk management will also be more prone to value emotional inputs. Moreover, emotions perceptions are at the base of our human social interactions, the capacity to express emotions and to perceive those of others playing the role of a social glue (Decety & Meyer, 2008). An individual with a higher openness to emotions will be more concerned by the fate of others in a risk management situation, and therefore would be considering public inputs, for example, more positively (Roeser, 2012a). Emotions, by revealing the salience of moral issues, especially regarding risk perceptions of new technologies characterized by high uncertainty and unpredictability, may also contribute to acknowledging the limits of an objective/technical approach to risk and the benefit of a constructivist/qualitative approach (Kraemer, 2010). Therefore we suggest that individuals' ERME will positively influence *emotional openness* (EO), which subsequently will limit *professional ethnocentrism* (PE).

Accordingly, our final research hypothesis is then:

H3: In a context of risk management, emotional openness (EO) will mediate the influence of ERME on professional ethnocentrism;

3.5. METHODOLOGY

3.5.1. Participants and procedures

To assess the influence of ethical risk-management efficacy on professional ethnocentrism and the role of emotions in this relation, engineers – active or retired – have been invited through the alumni network newsletter of a major Canadian engineering school to answer an online questionnaire. Table 15 presents the demographic and professional characteristics of the respondents. Overall, 178 respondents have completed our questionnaire. 77% are men, presenting an average of 50-59 years old, and having 20 to 25 years of experience in engineering (SD= 2.51) while declaring the frequency to which they engage in risk management practice to "occasionally" (SD= 1.41). As the survey has been massively sent to the alumni network, the actual response rate of our questionnaire is unknown, but our relatively small number of respondents may imply a low response rate. However, as we have targeted a very large population, the representativeness of our sample is much more important than the actual response rate (Cook *et al.*, 2000). By comparing the demographic characteristics of our sample and those of the population (Table 16), one can see that they are relatively similar, with a small over-representation of the 50-59 year and 60+-year categories, mainly to the detriment of the 30-39-year category. This may be interpreted that being more experienced, they are more concerned by risk management activities, and therefore might have been more motivated to participate in the study.

Table 15. Demographic characteristics of the respondents (N = 178)

	N	%
Gender		
Women	41	*23.0*
Men	137	*77.0*
Age (year)		
29 and less	15	*8.4*
30 - 39	34	*19.1*
40 - 49	41	*23.0*
50 - 59	50	*28.1*
60 and more	38	*21.4*
Engineering experience (year)		
Less than 2	5	*2.8*
2 - 5	17	*9.6*
5 - 10	14	*7.9*
10 - 15	16	*9.0*
15 - 20	19	*10.7*
20 - 25	22	*12.4*
25 - 30	33	*18.5*
30 - 35	17	*9.6*
35 - 40	22	*12.4*
More than 40	13	*7.3*
Risk management practice frequency		
Never	17	*9.6*
Rarely	35	*19.7*
Occasionally	61	*34.3*
Frequently	32	*18.0*
Most of the time	13	*7.3*
All the time	20	*11.2*

Table 16. Demographic characteristics of the population

	%
Gender	
Women	*24.0*
Men	*76.0*
Age (year)	
29 and less	*10.4*
30 - 39	*29.5*
40 - 49	*24.9*
50 - 59	*20.6*
60 and more	*14.7*

3.5.2. Measures

For this study, respondents were asked to answer 20 items on an agreement 5-point Likert scale (1= totally disagree, 5= totally agree) unless noted otherwise. Four variables are of interests for this study:

Risk management practice frequency. This is a one-item categorical measure, composed for this study, asking to which frequency the participant engage in risk management practice in their daily activities. Answers were reported on a six-item scale ranging from "never" to "all the time" (see Table 15).

Professional ethnocentrism. The measure, composed for this study, is a 5-item 5-point scale asking the participants to which extent they agree with the statements regarding the relevance of risk management perspectives from other experts and lay people. All items are shown in Table 17 with their corresponding mean and standard deviations. The internal consistency coefficient is, however, somewhat low (.61). This issue is addressed with an exploratory factor analysis later in the Results section.

Emotional openness. This scale has also been composed by the authors for this study. The participants were asked to rate the extent of their agreement on five items (5-point) representing the role and relevance of emotions in risk management. All items and their corresponding means and standard deviations are shown in Table 17. The internal consistency is satisfactory (.81).

Ethical risk management efficacy. For this measure, a 10-item scale has been developed based on the Moral efficacy scale from May *et al.* (2014) and following the recommendations of Bandura (2006) for the construction of self-efficacy scales. Participants were asked to rate their confidence in their ability to perform each of the tasks on a 5-point Likert scale where: 1= no confidence at all and 5= extremely confident. All items are shown in Table 17 with their corresponding mean and standard deviation, and the scale shows a good internal consistency (.89).

3.5.3. Analytical strategy

First, the item composition has been investigated using internal consistency analyses. Since any item was significantly and negatively affecting consistency, we suggest that the item composition is optimal. An item reduction phase was then unnecessary. However, since ERME is a newly composed scale and professional ethnocentrism shows suboptimal although acceptable consistency (Hair *et al.*, 1998), we propose to investigate an inter-item zero-order correlation analysis. Then, all items should correlate, or correlate stronger, with their intra-factor items. Moreover, we will use an exploratory factor analysis to investigate the construct and discriminant validity of all self-reported variables. This will bring robustness to our specifically designed variable ERME as well as to professional ethnocentrism. Finally, in order to test our hypotheses, H1 and H2 are going to be observed as bivariate correlations, while H3 is going to be tested using bootstrap technique (Hayes, 2013).

3.6. RESULTS

Table 17 regroups the means and standard deviations (S.D.) for each item composing PE, EO and ERME constructs. In average, engineers tend to disagree with professional ethnocentrism as the average for this construct is 2.3. It is, however, interesting to note that while they acknowledge the relevance of inputs from public and other experts, they still tend to agree that only the opinion of engineers is relevant in industrial risk management (PE4 = 3.56).

Concerning emotional openness, they seem to be in a neither-agree-nor-disagree position, as the average for this construct is 2.9. While they seem to struggle to decide if emotion can play a key role in risk management (EO1 = 2.9), they tend to disagree that they may be as relevant as scientific methods (EO2 = 2.7) and that emotional concerns should be integrated in the process of risk management (EO3 = 2.6), though these are not strong opinions. However, engineers are more in agreement with the fact that emotions may be a source of ethical reflections (EO4 = 3.4).

Finally, professional engineers seem to be rather confident in their ability to address specific tasks relevant for a more ethical approach of risk management, as the average for the ERME construct is 3.5. Particularly, they have rated the more positively their confidence in their capability to analyze a system (ERME1 = 3.8) and to recognize the transdisciplinary nature of risk assessment (ERME7 = 3.9). However, they are more or less confident in their capability to use the role of emotions to enhance industrial risk management (ERME5 = 3), which is coherent with their opinion regarding emotional openness.

Table 17. Descriptive results: ratings of agreement to statements composing professional ethnocentrism, emotional openness and ethical risk management efficacy constructs for professional engineers (N=178)

Construct	Items	Mean	S.D.
Professional Ethnocentrism (PE)	PE1. The opinion of the public is not relevant in industrial risk management.	2.07	0.84
	PE2. The opinion of non-technical experts (sociologists, psychologists, ethnologists, etc.) is not relevant in industrial risk management.	2.04	0.84
	PE3. In industrial risk management, it is useless to consider public opinion.	1.82	0.98
	PE4. Only the opinion of engineers is relevant in industrial risk management.	3.56	0.90
	PE5. Only engineers are able to identify all risks of an industrial project.	2.01	0.98
Emotional Openness (EO)	EO1. Emotions play a key role in industrial risk management.	2.87	0.99
	EO2. Emotions are as relevant as scientific methods for industrial risk management.	2.72	1.17
	EO3. Part of the risk management process in engineering should be based on emotional concerns toward industrial risks.	2.63	1.06
	EO4. In industrial risk management, emotions are a source of ethical reflections.	3.35	0.97
	EO5. It is important to be aware of our own emotions in industrial risk management.	3.09	1.03
Ethical Risk Management Efficacy (ERME)	ERME1. Analyze a system (industrial structure, process, project, etc.) to assess industrial risks.	3.81	0.79
	ERME2. Recognize ethics issues regarding risk management in engineering .	3.55	0.78
	ERME3. Recognize the interdependency of technical and non-technical dimensions in industrial risk management.	3.66	0.79
	ERME4. Recognize the need to integrate non-technical aspects in industrial risk management.	3.62	0.82
	ERME5. Use the role of emotions to enhance industrial risk management.	2.97	0.92
	ERME6. Analyze the limits of technical approaches in industrial risk management.	3.51	0.82
	ERME7. Recognize the transdisciplinary nature of industrial risk management.	3.92	0.82
	ERME8. Formulate technical and non-technical strategies to enhance industrial risk management.	3.56	0.76
	ERME9. Use divergence of opinions towards a risk to enhance its assessment and management.	3.55	0.82
	ERME10. Formulate strategies to reduce resistance towards non-technical approaches in industrial risk management.	3.16	0.84

3.6.1. Zero-order correlations and factor analysis

As suggested before, an inter-item zero-order correlation analysis has been executed, revealing that all items were correlated with their respective factors. When more than one coefficient was flagged as significant, the strongest was always intra-factor. Successively, an exploratory factor analysis using a varimax rotation has been tested on all items related to professional ethnocentrism (5-item), emotional openness (5-item) and ERME (10-item). Three factors were obtained with an eigenvalue higher than one and for an overall explained variance of 54.5%: PE (eigenvalue= 1.80; items loadings from .51 to 73), EO (eigenvalue= 3.11; items loadings from .67 to .84) and ERME (eigenvalue= 5.39; items loadings from .61 to .82). All items show loadings only with their respective factor. These results are summarized in Table 18.

Table 18. Exploratory factor analysis

Indicators	Factor loadings	Eigen Value	Variance explained (%)
Professional ethnocentrism (Mean = 2.3, SD = 0.57, α= 0.61)		1.8	8.98
PE1	.73		
PE2	.68		
PE3	.58		
PE4	.51		
PE5	.57		
Emotional Openness (Mean = 2.9, SD = 0.79, α= 0.81)		3.11	15.53
EO1	.73		
EO2	.67		
EO3	.75		
EO4	.75		
EO5	.84		
Ethical Risk Management Efficacy (Mean = 3.53, SD = 0.57, α= 0.89)		5.39	29.97
ERME1	.61		
ERME2	.72		
ERME3	.82		
ERME4	.76		
ERME5	.64		
ERME6	.66		
ERME7	.67		
ERME8	.73		
ERME9	.67		
ERME10	.71		

3.6.2. *Hypothesis testing*

In order to investigate the full mediation effect of emotional openness between ERME and professional ethnocentrism (H3), we have preliminarily explored inter-correlations. These results are summarized in Table 19.

Table 19. Inter-factor correlations among variables/constructs and Cronbach's α values

Variables/constructs	1	2	3	4	5	6	7
1. Gender	1						
2. Age	.35**	1					
3. Prof. exp.	.33**	.90**	1				
4. Risk man. frequency	.18*	.24**	.31**	1			
5. Prof. ethnocentrism	.07	.08	.05	.09	(.61)		
6. Emotional open.	-.09	.05	.06	.09	-.21**	(.81)	
7. ERME	.12	.22**	.26**	.56**	.05	.23**	(.89)

Notes: n= 178; *: p< .05; **: p< .01.

First of all, the frequency of risk management practice is correlated with professional experience (r= .31, n= 178, p < .01), suggesting that the more experienced an engineer is, the more regularly he or she will practice risk management, which makes practical sense. Indeed, the engineers' responsibility is minimal at the beginning of their career, as they are continuously supervised in the realization of their work. The more they gain in experience, the more their responsibility is involved and the risk management activity becomes therefore a more prevalent activity. Moreover, as they become more experienced, they have a better understanding of systems and process, which make them also more valuable for risk management activities. They are therefore more likely to be involved in such.

Second, risk management practice frequency is strongly related with ERME (r= .56, n= 178, p < .01), confirming our first hypothesis (H1). As suggested previously and in agreement with the self-efficacy theory, the more an individual is practicing risk management in his or her daily tasks, the more he or she is going to feel confident in his or her related abilities. Specifically in our case, the more an engineer is confronted to the complexity of risk management activities (i.e. the relevance of non-technical dimensions, of the public's opinion or of emotions), the more he or she will be confident in his or her capability to achieve efficiently related tasks in risk management.

Third, using only a bivariate correlation test, ERME is not significantly related to professional ethnocentrism ($r = .05$, $n = 178$, $p = .49$). Contrarily to our second hypothesis (H2), there is no direct relationship between these variables. A higher sense of self-efficacy regarding ethical risk management practices does not seem to be necessarily related to a lesser professional ethnocentrism.

In order to test our final hypothesis (H3), we used a bootstrap inference technique (Hayes, 2013) to test the full mediation of emotional openness between ERME (IV) and professional ethnocentrism (DV). Gender, age and years of experience in engineering were tested as control variables. Based on Preacher and Hayes' (2008) and Hayes' (2013) suggestions, a bootstrap technique was used in order to overcome the limits of Baron and Kenny (1986) and Sobel' (1982) tests. In an objective to obtain 95% bias-corrected confidence intervals (CI), we bootstrapped 5000 samples.

As a result, we observed an indirect effect of ERME on professional ethnocentrism through emotional openness as predicted by H3 (-.05, 95% CI= -.11, -.02). The direct effect of ERME on emotional openness is significantly positive ($\beta = .36$, $p = .01$). Thus, the higher the engineer's perceived confidence in his or her ability to achieve specific tasks that challenge his technical perspective in a risk management situation, the more likely he or she will be to consider and value emotions in the same situation. Moreover, the direct effect of emotional openness on professional ethnocentrism is significantly negative ($\beta = -.16$, $p = .01$), suggesting, as hypothesized, that the higher the openness to emotions in a risk management context, the more likely to consider opinions from the public and non-technical experts as well.

While we have previously suggested that risk management experience has a strong and significant influence on ERME, it does not, however, has a direct influence on emotional openness and professional ethnocentrism. This illustrates that individuals' experience influences their specific behaviors only through the perception of their capability to engage in such, which strengthen the relevancy of the self-efficacy based construct.

Finally, as observed in our preliminary correlation tests, ERME still does not show a significant direct relation with PE (β= .06, p= .22). Our final model is illustrated by Figure 8

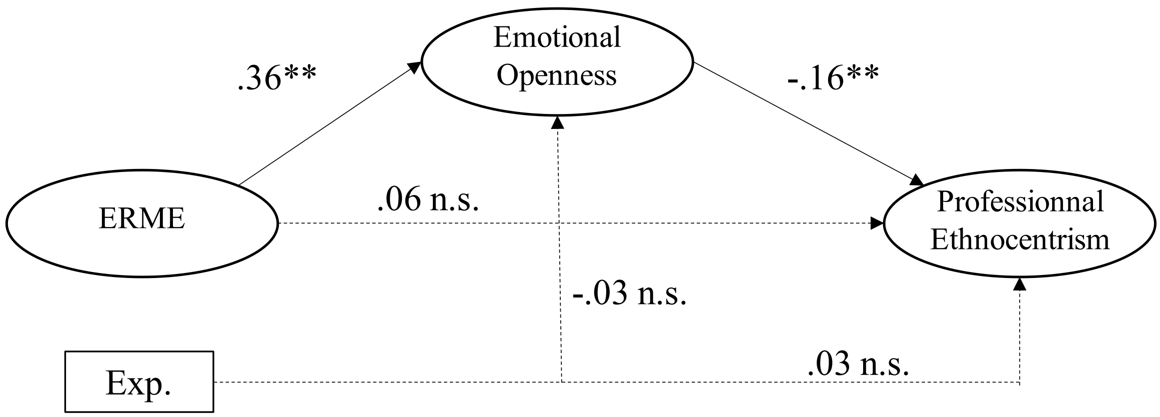

Figure 8. The effect of Ethical Risk Management Efficacy on Professional Ethnocentrism via Emotional Openness.

Notes: n.s.: not significant; **: p< .01;

3.7. DISCUSSION

In this empirical study, we have considered the influence of the ethical risk management efficacy (ERME) of engineers on their tendency to depreciate risk perspectives from other experts and lay people (PE), and the role of their emotional openness (EO) in this relation. As argued previously, an interdisciplinary and collaborative approach of risk management contributes to an ethical approach of risk management. Then, engineers should transcend their PE to benefit from the plurality of legitimate perspectives on risks and therefore promotes such approach. Our results suggest that ERME has a significant relationship with PE, fully mediated by emotional openness.

As the complexity of engineering projects increases, their success now more than ever lies on the collaboration between many different disciplines, which require the acknowledgement and the valorization of both "hard-" and "soft-" science perspectives. Moreover, as the sensibility of the public toward the potential negative social or environmental consequences of these projects increases along with their power to oppose them, engineers need to be sensitive to these issues and to be able to integrate them in the risk management process. In this regard, our study brings several interesting results, which also open research avenues deserving, we believe, deepening.

First, our results have illustrated that, in a context of engineering risk management, emotional openness helps limiting professional ethnocentrism, i.e. both the depreciation of risk perspectives from lay people and non-technical experts. We have argued before that public perspectives on risks are often considered by scientists and engineers are emotionally biased, and therefore irrelevant. Used to analytical-rational approaches, they may struggle to recognize their actual legitimacy. In light of our results and in agreement with Roeser (2012a), we suggest that emotional openness may indeed help engineers to "transcend a detached, abstract attitude that could lead to indifference to morally problematic aspects of technologies" (p.111), and therefore to adopt a perspective of responsibility that goes beyond the sole technical execution of risk management. This is, moreover, in agreement with the perception of the engineers of this study that emotions may be a source of ethical reflections. This emotional openness, by underlining dimensions that analytical and technical approaches in risk management struggle to consider, may also enhance sensitivity to non-technical dimensions and therefore legitimize “soft-” science perspectives on risk.

More importantly, our results suggest that such commitment to emotional openness is strongly influenced by the individual’s perceived ability to actually achieved tasks that challenge his or her technical perspective. It is therefore not only important to show or explain the potential benefits of specific values (here emotions and pluralism) to promote an ethical approach of risk management, it is also essential to actually empower engineers to deal with them. According to the self-efficacy theory and the results from several empirical studies presented in our literature review, self-efficacy can be promoted through training. However, to efficiently empower engineers to engage in and promote ethical reflections, such training should be representative of the complexity of the context in which they actually evolved (Bucciarelli, 2008; Conlon & Zandvoort, 2011) and should actively involve them (Felder *et al.*, 2000; Prince, 2004). However, as emotional openness is central here, they should not only be rationally involved, but also emotionally involved. Therefore, art-based approaches, and particularly role plays and dramas, could be mobilized as they have the capacity to address a wide range of human concerns and potentially promotes emotional and ethical reflections (Monk, 2009; Nussbaum, 2001; Roeser, 2012a; Shrivastava, 2010).

3.8. LIMITATION AND FURTHER RESEARCH

Several limitations has to be considered for this study. First, even if the representativeness of our sample has been confirmed using the available characteristics of the population, the relative small number of respondents is still a limitation of our research. If getting access to a large number of professional engineers was a challenge at first, acquiring completed surveys was a major one after. Several reminders of the invitation to participate have been sent to maximize our response rate. However, targeting several specific industrial organizations instead of using an alumni network could have enhanced our response rate.

Second, while EO and ERME constructs show satisfactory internal consistencies, PE’s coefficient, however, is somewhat low. Although it is still acceptable for a construct under development (Hair *et al.*, 1998), it should be consolidated by revising our items. Also, our study has compared self-efficacy level among individuals who have surely not been influenced by the same professional experiences. It would then be interesting to study longitudinal effects by following teams involved in risk management within selected industrial projects, which would also allow to enrich and nuance our results using participant observation and interviews. This would also be an opportunity for cross-level analyses using organizational and interpersonal factors, such as perception of organizational ethics practices and ethical leadership, which would surely enrich our understanding of our model.

Finally, in order to analyze the robustness of our model and to expand its application, we invite researchers to test it in another safety sensitive domain, where emotions, pluralism and self-efficacy are relevant, such as, for example, the medical or public health fields.

Conclusion

Risk management is a deeply value-laden activity. It is important, to approach this activity more ethically, to limit professional stereotypes and cognitive bias on risks. To do so, engineers should be sensitive to the pluralism of legitimate perspectives on risks as well as the potential benefit role of emotions. More importantly, they should be empowered to address these issues effectively.

We have suggested in this study that self-efficacy on ethical risk management positively influences emotional openness, which, in return, has the potential to significantly limit professional ethnocentrism, which is essential for the development of effective interdisciplinary and deliberative approach of risk management.

While interdisciplinary and ethical competences are now required to be developed by engineering education, our results suggest that a specific emphasis should also be done on the role of emotions on risks perception and moral risk judgment. Courses combining lessons from neuroscience research on decision-making and social studies on risks and using art-based approaches, role plays and dramas as pedagogical tools may certainly support such a project.

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General Conclusion

Why industrial disasters keep happening? What do we miss, as engineers and managers, when designing, operating and managing these technologies? And maybe more importantly, can we do better? Those were the original questions that motivated this thesis by articles in the first place. It has been argued, in the first chapter, that a shift toward a complex and ethical mindset in risk management would certainly contribute to more responsible and safer practices in engineering. Since it has been suggested that the ethical limitations of the technical approaches in safety engineering appear to have emerged from the fragmentation of the profession, the main objectives of this research were 1) to evaluate to what extent current engineering education and practice empower individuals into an ethical approach of risk management and 2) to determine how ethical pluralism, applied to risk management, could enhance this empowerment.

The three articles constituting this thesis have brought some elements of answer and have therefore contributed to achieving these goals. As each article has its own discussion and conclusions parts, the purpose of this final chapter is mainly to synthesize the findings and relate them in order to conclude with a coherent whole, while addressing more general reflections. The main limitations of this thesis as well as avenues for further research will finally be discussed.

Overview and general discussion of research

As officially stated in most engineering ethics codes, safety is the first responsibility in engineering (NSPE, 2015). We would therefore expect that such essential dimension be addressed and developed in the curriculum (Amyotte & McCutcheon, 2006). It has then been very surprising to observe that so few articles in engineering education focus on this essential dimension. Of course, as pointed out before, not every lesson content or pedagogical material is the object of publications. Then the analysis of published articles may only give a limited representation of what is actually done in classrooms. But this observation does illustrate, however, that reflections regarding safety training in the engineering curriculum are limited, which may be interpreted as a lack of willingness to question and develop this dimension.

To be fair, one may indeed doubt the relevance and usefulness to do so, and argue that such competency will be developed later on the field, once students have acquired a practical knowledge about industrial reality. Of course, by definition, students lack of field experience. It is true for every aspect of their future practice. And yet they are still trained in process design for example, often in a preliminary fashion which does not reflect the industrial reality either. Does that mean that design should not be included and developed in their curriculum? Besides, in a more pragmatic fashion, education does not imply undergraduate training only, but also continuous professional education for example, wherein individuals have significant field experience and for whom such training might be relevant.

But this actually raises a much more fundamental question: what is the purpose of engineering education? Is it to produce only an executive workforce or is it also to train responsible world citizens? If the latter is assumed, which is the case in this thesis, is this responsibility fulfilled by the sole technical execution of risk management? The deontological nature of the predominant relationship between ethics and risk management in the engineering education literature implies that this may be the case, which is consistent with the classic engineer's paradigm for which the locus of responsibility is risk management (Kermisch, 2012). However, the ethics limitations of the technical approaches discussed throughout this thesis suggest that, on the contrary, practising risk management is not sufficient to be responsible, for it still has to be done in a responsible way. The capacity of ethical reflection of the engineers in a context of risk management therefore has to be developed.

For this purpose, several propositions have been identified in selected articles in the engineering education literature presenting a deep relationship between ethics issues and risk management. In particular, it has been suggested to increase the level of complexity of the scenarios used to teach risk management and ethics, through, for example, the inclusion of the organizational, social, political and cultural dimensions, as well as the integration of multiple systems of values. Since these very relevant suggestions were, however, mainly focused on decision-making, it has been argued that they should also target the whole process, from risk identification to data collection, communication and evaluation, in order to address more efficiently ethics issues in risk management.

Multidisciplinary training has also been suggested in some articles to enhance the valorization of multiple perspectives. That implies that professional specialization might induce several biases. However, the question whether engineering education might indeed influence assumptions regarding specific ethical aspects in risk management was not addressed in the literature analyzed. This was therefore one of the objects of the second article. Comparing the level of agreement of 200 first and last year students on four different constructs in a context of risk management (Emotions, Reductionism, Determinism and Deontology), it has been suggested, within the results' limits, that the engineering training does not induce the anticipated fragmentation. While, in this context, this has been interpreted positively, it has, however, been also suggested that such training does not increase the self-perceived capacity of students to efficiently approach risk management ethically. Students then, although being sensitive to ethical aspects of risk management, are not empowered to deal with such dimensions. It has been argued that eventually, this may trigger a ethical disengagement while learning technical risk management practices in their organizational context, especially if such relation is not acknowledged or valorized.

Therefore, as the general purpose of this thesis was to contribute to the development of more empowered engineers in ethical risk management, workshops have been developed in coherence with the propositions identified in the literature – more complexity, multiple system of values – using ethical pluralism as a theoretical frame, as well as active learning as a practical frame. Each workshop has been designed to target in priority specific ethics aspects of risk management using specific dominant values (complexity, dialogue and emotions). The risk there was to end up with fragmented workshops, which would have been inconsistent with the mindset of this thesis. Nonetheless, because they were based on active learning, workshops were themselves complex situations, with emergent and co-constructed knowledge, which allowed to interweave targeted dimensions. For example, the emotional aspect was not limited to the third workshop. Indeed, because students were asked to personify citizens and scientists in a debate over risks analysis results related to the eventual pollution of an urban area, the role-play activity of the second workshop also had an important emotional loading. As well, the complexity of the case analyzed in the first workshop underlined the necessity of a collaborative and deliberative approach of risk management. Finally, as very well illustrated by some of the selected rich pictures presented in Appendix A, complexity also emerged in the creative art-making workshop. Then, in the mindset of this thesis, the proposed workshops constitute an inseparable whole.

Within the limits of this thesis results, it has therefore been suggested that the engineering training does not significantly influence self-efficacy in ethical risk management, but what about the professional practice? And how is self-efficacy related to the perception of specific ethics issues in a risk management context? These reflections were at the foundation of the third and final article. Based on the participation of 178 professional engineers to the thesis survey, it has been observed that the experience of risk management has a positive influence on self-efficacy in ethical risk management, concept coined Ethical risk management efficacy in this article. This was an expected result. Indeed, while it has been argued that the technical methods do not match adequately the complexity of industrial activities, engineers surely face this complex reality while practising risk management, which may invite them to acknowledge and valorize non-technical dimensions by force of practice. This result strengthens then the relevancy of the workshops, since they seem to simulate experience, which therefore would allow engineers to be more empowered sooner in their career.

Finally, it has also been suggested that ethical risk management efficacy has an indirect but significant influence on professional ethnocentrism, through emotional openness in a risk management situation. More precisely, individuals with higher ethical risk management efficacy will tend to be more motivated to acknowledge and valorize the role of emotions, which, in return, will reduce the propensity to depreciate the risks perspectives from other, non-technical, experts, as well as from lay people. Consistently with a large body of scientific literature, this result illustrates the need to valorize the potential benefit role of emotions in science in general and engineering in particular, as well as their managements. As it will be developed in the next section, this interesting results has also direct practical implications, especially for the development of consistent Corporate Social Responsibility (CSR) practices in industrial organizations. The other contributions of this thesis will also be discussed, along with its limitations and the propositions for further research.

Contributions

This thesis by article offers several contributions, both to the theory and to the practice of risk management as well as engineering education. First, from a theoretical perspective, this thesis as a whole contributes to the **ethical perspective in risk management** by proposing a pluralistic approach directly related to specific identified limits of the technical methods used in engineering. This approach differs from other recent ethical frameworks (e.g. Patenaude *et al.*, 2014) in several ways. First, it does not focus solely on risk acceptability but rather invite to reflect on the whole process of risk management by questioning the deterministic paradigm on which usually lies traditional approaches. Secondly, it does not impose specific values to structure this questioning, but promotes instead a process of co-construction of these emergent values, through expert collaboration, public deliberation and emotional reflections, which is more consistent with a pluralistic perspective of ethics.

More specifically, this thesis contributes to the **engineering education literature** by presenting the first systematic review of the nexus between ethics and risk management and by proposing an analysis of the nature of this relation. This review has allowed identifying relevant propositions, as well as points to develop, in order to promote such connection. Furthermore, this thesis also contributes to this body of literature by proposing the first empirical analysis of the influence of engineering education on specific assumptions regarding ethical dimensions in risk management, which nuance the stereotypical portrait of the engineer usually found in the literature. Also, while the concept of self-efficacy has been regularly used in an engineering education context, it is the first time that, to the best of my knowledge, it is related to ethics and risk management, on the one hand, and that the influence of the engineering training as a whole on self-efficacy is analyzed, on the other hand.

Moreover, besides the general contribution to the development of an ethical approach of risk management, this thesis also contributes to the **safety literature** by proposing a new self-efficacy scale linking ethics and risk management, and by applying it specifically to the engineering community. One last contribution to this field is the empirical analysis of the eventual positive role of emotional reflection for the development of a cooperative and deliberative approach of risk management, which also contributes to the wider multidisciplinary body of literature studying the role of emotions in rationality.

Secondly, from a practical perspective, this thesis by article contributes to the **engineering education practice** by proposing an innovative training approach of ethical risk management based on ethical pluralism and using relevant active learning approaches, such as complex case analysis, role play and creative art-making. This approach has been shown efficient, at least in the short run, to develop critical questioning in general, but also to enhance self-efficacy in ethical risk management in particular. Such training could be directly implemented into the regular curriculum and/or proposed in the continuous professional education program. Also, the self-efficacy scale developed in this thesis could be used as a performance indicator for other training. Furthermore, the analysis of the role of emotional openness in the relation between ethical risk management efficacy and professional ethnocentrism has also concrete implications, since it underlines the relevance to integrate emotional reflections into multidisciplinary training.

Last but not least, this thesis also offers some concrete contributions to the **organizational practice**. First, in this field too, the ethical risk management efficacy scale can be used as an indicator to assess and predict ethical performance in a context of risk management. Also, this thesis contributes to the promotion of emotional reflections as a legitimate tool of ethical reflections in safety practice. Indeed, I had the opportunity, as part of a parallel project, to make several interviews with top managers in the Oil and Gas industry. One of my respondents, when asked how they assess that in a risk management context, they are doing "the right thing" (to use his own vocabulary), has answered with the following:

> “It's always going to come back to that human level at the end of the day. That is the ultimate test. Whenever we got a situation, I have always had in my mind, would I ask my son to go and do that. And if I can't say yes, I am not gonna ask anybody else. To me that's the real test, [that’s] how high are the ethical standards of the company, and how human are they.”

Another respondent, when discussing about ethics in the organization, has told me some advice he received from the previous CEO:

> “ ‘If it feels wrong, it probably is wrong’. And I have never forgotten that, because actually, in almost every single situation I have found myself, when I had this uncomfortable feeling inside about something, and I sat down and I talk about it directly to someone, it turned out to be you shouldn't do it. So if it feels wrong, if you own self is telling you: listen this is... If you find yourself trying to justify it, [...] It is probably wrong and you should not do it.”

These statements illustrate that emotions are not rejected in the process of decision-making, on the contrary. This thesis then, brings empirical justifications not to keep such reflections to the individual instinctive level, but instead to develop an organizational rationality of emotional reflections.

Finally, this thesis, through its analysis of the relation between professional ethnocentrism, ethical risk management efficacy and emotional reflections, may contribute to the promotion of CSR practices, especially in the oil and gas (O&G) industry, by reducing the gap between the community relations and safety area. For example, in their recent analysis of CSR practices in the mining and oil and gas industries, Raufflet *et al.* (2014) have identified several inconsistencies. Indeed, while 100% of the O&G companies which have been analyzed have conducted risk analyses of their process, the establishment of CSR practices regarding the community relations area is still underdeveloped. For example, if 70% of the companies have published specific commitments toward the communities, just 30% have signed agreement with them or participate to locally coordinated approach and only 10% have recognized and respected the principle of free, prior and informed consent of the communities. This illustrates mainly a top-down relation, and means that the industry, in average, still accept the risks inherent to their industrial activity on behalf of the local communities. The perspectives developed in this thesis may help them make their CSR practices more consistent.

Limitations and further research

Like any other research work, this thesis shows several limitations, while also offering avenues for research further. As for the previous section, some of them have already been discussed within each article. This final section will then give the opportunity to address other, more global limitations and avenues for further research.

The first main limitation is related to the questionnaire developed for both articles 2 and 3. Despite the precautions taken for its development, as well as the pre-tests, the relatively low rate of participation both of students and professionals illustrates that there is still room for improvement. Since the youngest individuals within the targeted population has at least a collegial education, the text readability of the survey is not an issue in itself (Schwarm & Ostendorf, 2005). However, the content and construct validity of the part of the survey related to ethical aspects of risk management would surely be improved by the reformulation of several items. This would also enhance the internal consistency of some constructs, such as Determinism in article 2 or Professional Ethnocentrism in article 3. As well, regarding the self-efficacy scale, the deliberative dimension of risk management has been implicitly assumed within the non-technical dimension or the notion of divergence of opinions. It would be important, before the practical implementation of the scale, to reformulate some items to explicitly address this aspect.

Also, the whole survey should be streamlined to target exclusively these constructs. Indeed, preliminary questions have been developed in order to gather complementary data which at the end of the day have not even been used for this thesis. Even if it was clearly indicated that the answer to these questions was not mandatory, they have surely negatively influenced the participation rate, as 28.2 % of the participating individuals have dropped the survey while answering them. In comparison, only 5% of the individuals have dropped while answering the main questions. Although for a large population representativeness is more important than the response rate (Cook *et al.*, 2000), it seems that it would still have been possible to improve it, which certainly would have contributed to more robust results.

Concerning the workshops, the main limitation is related to the difficulty of execution of the creative art-making activity. To be more precise, the execution in itself was not that difficult, since students, after a moment of surprise and hesitation, usually have engaged the activity with enthusiasm. But it was hard for them to understand what they had to do, what was expected, and how to engage in emotional reflection through art-making. In order to ease or maybe trigger this process, a slideshow of selected pictures of both great engineering realizations and industrial disasters has been prepared. However, based on what has been observed and on the focus group discussions, the efficiency of such strategy was not clear. Instead, the emergence of the connections between workshops should have been better valorized and the emotional arousal they have experienced during the second workshop should have been more mobilized. It may have given them a more personalized and concrete based to start their reflection. Further study on these workshops could help verify this proposition.

Also, while article 3 gives an interesting base for a better understanding of how self-efficacy and emotional reflections may promote a cooperative and deliberative approach of risk management in engineering, the model proposed should be consolidated and developed in further research. Indeed, ethical behaviours are influenced by several organizational, interpersonal and individual factors (Treviño *et al.*, 2014). Variables representing these factors, such as ethical leadership and perception of organizational ethics practices may be included. Also, emotion-based variables, such as emotional intelligence and empathy, should be integrated in order to get a better understanding of the emotional openness construct.

Moreover, it has been suggested that Ethical risk management efficacy influences Emotional openness and, indirectly, Professional ethnocentrism. However, the degree of agreement to the Emotional openness and Professional ethnocentrism constructs is not a measure of actual behaviours, only behavioural intentions (Eyal *et al.*, 2009). Also, it has also been suggested that the proposed workshops efficiently influence Ethical risk management efficacy. But this efficiency is still hypothetical since no observation of actual behaviours change in risk management practices has been made. Then, an important research avenue would be to involve professional engineers in these workshops and then to assess and analyze their practical, long-term efficiency on real risk management practices in industrial projects using a longitudinal mixed approach based on the observation of actual behaviours and surveys. Such study could be made within a CSR theoretical framework, and would therefore help developing the potential contribution discussed before. Finally, the analysis of the organizational determinants which could promote, or conversely limit, an ethical approach of safety would certainly contribute to the development of programs of ethical risk management in industrial organizations.

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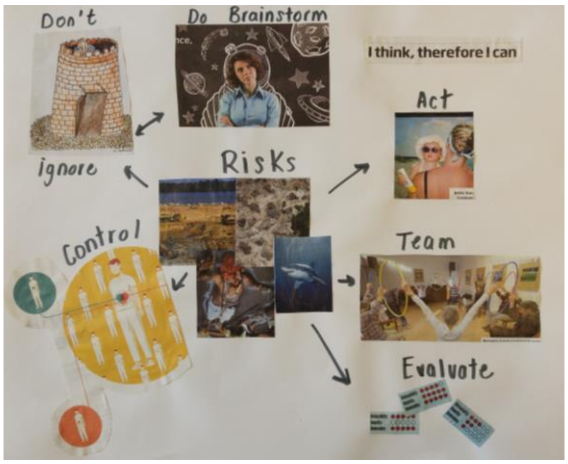
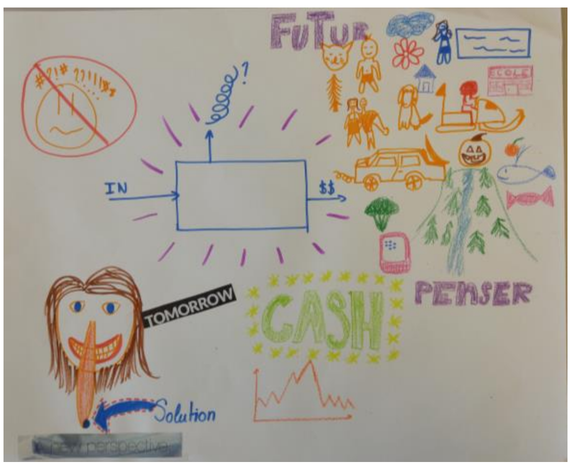
APPENDIX A – SELECTED RICH PICTURES FROM CREATIVE WORKSHOP




Inform.
educate,
cure
Antarctic ice is fading ever faster
No more pauses in global warming

Perceptions
Analyse
Multidisciplinaire
SANTÉ
Culture
Sécurité
ÉCHANGE
INTÉRÊTS
COMPLEXITÉ
CHOIX
Futur
Bien-être
Émotions
Risques
Humain
Angoisse
Société
COMMUNICATION
Environnement
URGENCE
Recherche
Perspectives
PASSÉ
Conséquences
David Bowie
ERREURS
Équipe
FUTUR

FUTUR
IN
$$
ÉCOLE
TOMORROW
CASH
PENSER
Solution

BOOM!!
EMOTIONS
BRAIN

Future.
Present!



Moral dilemma
404
GET LUCKY
FUCK
STRESS!
IMPUISSANCE
WORDS
NO
HOW TO THINK ABOUT EVERYTHING
SHH
Critical thinking

APPENDIX B – ONLINE SURVEY

Questionnaire

1 Sélecteur de langue

QUESTIONNAIRE SUR LA GESTION DES RISQUES INDUSTRIELS

2 Début 1

QUESTIONNAIRE SUR LA GESTION DES RISQUES INDUSTRIELS

Vous trouverez ci-après le questionnaire auquel vous avez été invités à répondre. Il a été développé par la Chaire de management éthique de HEC Montréal grâce à l'appui financier des Fonds de recherche sur la société et la culture du Québec (FRQSC). Il est autorisé et appuyé par l'Association des Diplômés de [redacted]

Répondez sans hésitation aux questions incluses dans ce questionnaire, car ce sont vos premières impressions qui reflètent généralement le mieux votre pensée. Ce questionnaire prendra environ entre 10 et 12 minutes de votre temps. Les résultats de ce questionnaire serviront au développement de la formation et de la pratique d'ingénierie en proposant de nouvelles approches systémiques dans les pratiques de gestion du risque industriel utilisées en ingénierie.

Vous êtes libre de refuser de répondre à ce questionnaire et vous pouvez décider en tout temps d'arrêter de répondre aux questions. Un questionnaire non complété ne pourra cependant pas être traité. Au besoin, vous pouvez interrompre votre session et cliquer à nouveau sur le lien vers le questionnaire à partir du même ordinateur pour continuer là où vous vous étiez arrêtés. (Attention: votre navigateur doit accepter les cookies afin de pouvoir quitter votre session et la continuer plus tard.)

Le fait de compléter ce questionnaire sera considéré comme votre consentement à participer à notre recherche et à l'utilisation des données recueillies dans ce questionnaire. Puisque le questionnaire est anonyme, une fois votre participation complétée, il vous sera impossible de vous retirer du projet de recherche, car il sera impossible de déterminer quelles réponses sont les vôtres.

Confidentialité

Les renseignements recueillis sont et resteront strictement confidentiels; ils ne seront utilisés que pour l'avancement des connaissances et la diffusion des résultats globaux dans des forums scientifiques ou professionnels. Le fournisseur de collecte de données en ligne s'engage à ne révéler aucune information personnelle.

Si vous avez des questions concernant cette recherche, vous pouvez contacter le chercheur principal, Yoann Guntzburger, au numéro de téléphone ou à l'adresse de courriel indiqués ci-dessous. Les comités d'éthique de la recherche de HEC Montréal et de [redacted] ont statué que la collecte de données liée à la présente étude satisfait aux normes éthiques en recherche auprès des êtres humains (N° de projet 2016-1812, CER 14/15-41). Pour toute question en matière d'éthique, vous pouvez communiquer avec le secrétariat de ce comité (HEC) au (514) 340-6051 ou par courriel à cer@hec.ca.

Merci de votre précieuse collaboration!

Yoann Guntzburger, Ing. Jr., M.Sc.A.
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HEC Montréal
514-340-6375
yoann.guntzburger@hec.ca

3 Questions préliminaires (1/3)

PREMIÈRE PARTIE: Questions préliminaires

Commençons par quelques questions préliminaires

1. Indiquez s'il vous plait votre statut actuel.

- Étudiant(e) en ingénierie
- Ingénieur(e) en exercice

4 Questions préliminaires (2/3)

2. En vous basant sur votre opinion personnelle et/ou votre expérience, évaluez l'importance de la menace associée aux risques suivants:

Répondez instinctivement. La première idée est souvent celle qui correspond le mieux à votre opinion. (La page suivante chargera automatiquement lorsque toute les questions auront été répondues.)

	Aucune importance	Peu important	Moyennement important	Très important	Extrêmement important
1. Risques financiers (associés au marché, au crédit, aux monnaies, de liquidité, etc.)	○	○	○	○	○
2. Risques environnementaux	○	○	○	○	○
3. Risques de réputation	○	○	○	○	○
4. Risques industriels (explosion, fuites, incendies, etc.)	○	○	○	○	○
5. Risques de régulation (mise en place de nouvelles lois, etc.)	○	○	○	○	○
6. Risques associés aux matières premières (manque de matières premières, changement de composition des matières premières,etc.)	○	○	○	○	○
7. Risques politiques (changement de gouvernement dans le pays d'origine ou dans les pays hôtes des activités de l'organisation, sanctions envers des pays hôtes, etc.)	○	○	○	○	○
8. Risques associés aux informations (fuites d'informations stratégiques, défaillance de réseaux d'informations, etc.)	○	○	○	○	○
9. Risques humains (perte d'employés clés, manque de compétence, problème de renouvellement de personnel, etc.)	○	○	○	○	○
10. Risques de compétition des autres organisations concurrentes	○	○	○	○	○

5 Questions préliminaires (3/3)

Intéressons-nous maintenant plus particulièrement aux risques industriels et à leur gestion

(Si vous éprouvez des difficultés à répondre à ces deux questions, vous pouvez les passer en inscrivant N/A et en cliquant sur suivant)

3. Qu'est-ce que pour vous la gestion du risque industriel?

Décrivez très simplement ce que représente pour vous la gestion du risque industriel. Cela peut être un mot, une idée, etc. Répondez le plus intuitivement possible.

4. Selon vous, quel élément est le plus important dans la gestion du risque industriel?

Là également, répondez le plus intuitivement possible (un mot, une idée, etc.)

6 Gestion des Risques Industriels (1/6)

DEUXIÈME PARTIE : La gestion des risques industriels (1/6)

1. En vous basant sur votre opinion personnelle et/ou votre expérience, indiquez, pour chaque proposition, votre degré d'accord ou de désaccord en sélectionnant votre choix.

(La page suivante chargera automatiquement lorsque toutes les questions auront été répondues.)

	Tout à fait en désaccord	Plutôt en désaccord	Ni en accord/ ni en désaccord	Plutôt en accord	Tout à fait en accord
1. Il est toujours possible d'identifier les risques industriels en décomposant les systèmes que l'on analyse.	○	○	○	○	○
2. On peut calculer de façon objective les conséquences de chaque décision relatives aux risques industriels.	○	○	○	○	○
3. Les émotions sont autant pertinentes que les méthodes scientifiques pour la gestion des risques industriels.	○	○	○	○	○
4. Les décisions politiques, l'environnement naturel, le contexte social et la culture ne sont pas des sources de risques industriels.	○	○	○	○	○
5. En gestion des risques industriels, il est inutile de considérer l'opinion publique.	○	○	○	○	○

7 Gestion des Risques Industriels (2/6)

DEUXIÈME PARTIE : La gestion des risques industriels (2/6)

2. En vous basant sur votre opinion personnelle et/ou votre expérience, indiquez, pour chaque proposition, votre degré d'accord ou de désaccord en sélectionnant votre choix.

(La page suivante chargera automatiquement lorsque toutes les questions auront été répondues.)

	Tout à fait en désaccord	Plutôt en désaccord	Ni en accord/ ni en désaccord	Plutôt en accord	Tout à fait en accord
6. Le code de déontologie garantit une gestion éthique des risques industriels.	○	○	○	○	○
7. Le calcul statistique garantit une évaluation objective et universelle des risques.	○	○	○	○	○
8. Seuls les ingénieurs peuvent identifier les risques	○	○	○	○	○

industriels d'un projet.

9. La gestion des risques industriels doit être basée uniquement sur des méthodes rationnelles.	○	○	○	○	○
10. Le code de déontologie sert de référence en gestion des risques industriels.	○	○	○	○	○

8 Gestion des Risques Industriels (3/6)

DEUXIÈME PARTIE : La gestion des risques industriels (3/6)

3. En vous basant sur votre opinion personnelle et/ou votre expérience, indiquez, pour chaque proposition, votre degré d'accord ou de désaccord en sélectionnant votre choix.

(La page suivante chargera automatiquement lorsque toutes les questions auront été répondues.)

	Tout à fait en désaccord	Plutôt en désaccord	Ni en accord/ ni en désaccord	Plutôt en accord	Tout à fait en accord
11. L'avis d'experts non techniques (sociologues, psychologue, ethnologue, etc.) n'est pas pertinent pour la gestion des risques industriels.	○	○	○	○	○
12. L'évaluation des risques industriels ne doit pas tenir compte du contexte politique, culturel, social et environnemental.	○	○	○	○	○
13. Les méthodes scientifiques utilisées en gestion des risques industriels résultent de choix objectifs.	○	○	○	○	○
14. L'avis de la population civile n'est pas pertinent pour la gestion des risques industriels.	○	○	○	○	○
15. La prise de décision relative aux risques industriels doit être basée sur le code de déontologie.	○	○	○	○	○

9 Gestion des Risques Industriels (4/6)

DEUXIÈME PARTIE : La gestion des risques industriels (4/6)

4. En vous basant sur votre opinion personnelle et/ou votre expérience, indiquez, pour chaque proposition, votre degré d'accord ou de désaccord en sélectionnant votre choix.

(La page suivante chargera automatiquement lorsque toutes les questions auront été répondues.)

	Tout à fait en désaccord	Plutôt en désaccord	Ni en accord/ ni en désaccord	Plutôt en accord	Tout à fait en accord
16. Une partie du processus de gestion des risques doit être basée sur les préoccupations émotionnelles des ingénieurs envers les risques industriels.	○	○	○	○	○
17. Le contexte culturel structure l'évaluation des risques industriels.	○	○	○	○	○
18. L'évaluation des risques industriels doit être basée sur la décomposition et la modélisation du système analysé.	○	○	○	○	○
19. Les ingénieurs sont les mieux placés pour la gestion des risques industriels.	○	○	○	○	○
20. En gestion des risques industriels, les émotions sont une source de réflexion éthique.	○	○	○	○	○

10 Gestion des Risques Industriels (5/6)

DEUXIÈME PARTIE : La gestion des risques industriels (5/6)

5. En vous basant sur votre opinion personnelle et/ou votre expérience, indiquez, pour chaque proposition, votre degré d'accord ou de désaccord en sélectionnant votre choix.

(La page suivante chargera automatiquement lorsque toutes les questions auront été répondues.)

	Tout à fait en désaccord	Plutôt en désaccord	Ni en accord/ ni en désaccord	Plutôt en accord	Tout à fait en accord
21. Il est possible de supprimer totalement les risques industriels par des dispositifs techniques (mécaniques, électroniques, etc.).	○	○	○	○	○
22. Un renforcement du code de déontologie est nécessaire en cas de mauvaise gestion des risques industriels.	○	○	○	○	○
23. Les émotions jouent un rôle clé dans la gestion des risques industriels.	○	○	○	○	○
24. Tous les risques industriels sont causés par des aspects techniques des systèmes.	○	○	○	○	○
25. Il est toujours possible de remonter à la source d'un risque par une analyse des causes et des conséquences de ce risque.	○	○	○	○	○

11 Gestion des Risques Industriels (6/6)

DEUXIÈME PARTIE : La gestion des risques industriels (6/6)

6. En vous basant sur votre opinion personnelle et/ou votre expérience, indiquez, pour chaque proposition, votre degré d'accord ou de désaccord en sélectionnant votre choix.

(La page suivante chargera automatiquement lorsque toutes les questions auront été répondues.)

	Tout à fait en désaccord	Plutôt en désaccord	Ni en accord/ ni en désaccord	Plutôt en accord	Tout à fait en accord
26. L'évaluation des risques industriels est nécessairement subjective puisque chaque personne conçoit le risque différemment.	○	○	○	○	○
27. L'utilisation du code de déontologie est essentielle en gestion des risques industriels.	○	○	○	○	○
28. Les émotions doivent être prises en compte dans la gestion des risques industriels.	○	○	○	○	○
29. Les risques industriels d'un projet ne peuvent être évalués qu'en fonction des bénéfices potentiels de ce projet.	○	○	○	○	○

12 Questions Self-Efficacy (1/3)

TROISIÈME PARTIE: Questions générales sur votre confiance en vos habiletés éthiques et de gestion des risques

Passons maintenant à quelques questions portant sur votre confiance en vos habiletés éthiques et de gestion des risques.

13 Questions Self-Efficacy (2/3)

TROISIÈME PARTIE: Questions générales sur votre confiance en vos habiletés éthiques et de gestion des risques (1/2)

1. Ces questions portent sur votre confiance dans vos capacités éthiques

(La page suivante chargera automatiquement lorsque toutes les questions auront été répondues.)

Comment évaluez-vous votre confiance dans votre habileté à:

	Aucune confiance	Peu confiance	Moyennement confiance	Très confiance	Extrêmement confiance
1. Concilier vos obligations de protection et d'intérêt du public avec vos obligations de discrétion envers votre employeur ou client.	○	○	○	○	○
2. Représenter votre équipe de travail lors de réunions avec la direction concernant des enjeux éthiques.	○	○	○	○	○
3. Concevoir de nouvelles procédures d'évaluation pour les enjeux éthiques dans votre équipe de travail.	○	○	○	○	○
4. Faire des suggestions à la direction sur les façons d'améliorer le travail dans votre équipe concernant des enjeux éthiques.	○	○	○	○	○
5. Reconnaître les dimensions potentiellement positives et négatives de différentes perspectives éthiques.	○	○	○	○	○
6. Concilier des perspectives éthiques différentes.	○	○	○	○	○
7. Présenter à un groupe de collègue plusieurs alternatives pour une prise de décision éthique en réponse à l'analyse des conséquences positives et négatives de celles-ci.	○	○	○	○	○
8. Formuler une évaluation des différents aspects d'un enjeu éthique.	○	○	○	○	○
9. Formuler des stratégies pour limiter la résistance à vos solutions proposées concernant des enjeux éthiques au travail.	○	○	○	○	○
10. Reconnaître et analyser une situation présentant des enjeux éthiques afin de trouver une/des solution(s).	○	○	○	○	○
11. Distinguer la déontologie, la loi, la morale et l'éthique.	○	○	○	○	○

14 Questions Self-Efficacy (3/3)

TROISIÈME PARTIE: Questions générales sur votre confiance en vos habiletés éthiques et de gestion des risques (2/2)

2. Ces questions portent sur votre confiance dans vos capacités en gestion éthique des risques

(La page suivante chargera automatiquement lorsque toutes les questions auront été répondues.)

Comment évaluez-vous votre confiance dans votre habiletés à:

	Aucune confiance	Peu confiance	Moyennement confiance	Très confiance	Extrêmement confiance
1. Analyser la complexité d'un système (procédé, structure, etc.) afin d'en évaluer les risques industriels.	○	○	○	○	○
2. Reconnaître les enjeux éthiques liés à la gestion des risques industriels.	○	○	○	○	○
3. Reconnaître l'interdépendance des dimensions techniques et non techniques dans la gestions des risques industriels.	○	○	○	○	○
4. Reconnaître l'importance des dimensions non techniques de la gestions des risques industriels.	○	○	○	○	○
5. Utiliser le rôle joué par les émotions pour améliorer la gestion des risques industriels.	○	○	○	○	○
6. Analyser les limites des méthodes techniques de gestion des risques industriels.	○	○	○	○	○
7. Reconnaître la nature transdisciplinaire de la gestion des risques industriels.	○	○	○	○	○
8. Formuler différentes stratégies (techniques et non techniques) pour développer la gestion des risques industriels.	○	○	○	○	○
9. Tirer profit des différences de perceptions d'un risque pour en améliorer la gestion.	○	○	○	○	○
10. Formuler des stratégies pour limiter la résistance à des approches non techniques à la gestion des risques industriels.	○	○	○	○	○

15 Questions Complémentaires

QUATRIÈME PARTIE : Questions complémentaires

1. Répondez en sélectionnant votre choix

	Non, pas encore	Je le commence tout juste cette session	Je suis en train de le terminer	Oui, la session passée ou avant
51. Avez-vous déjà suivi le cours d'éthique offert à l'École (SSH550X)?	○	○	○	○

	Non, jamais	On en a déjà parlé un peu dans quelques cours	Oui, un module de plusieurs heures dans un ou des cours	Oui, un cours au complet ou une formation intensive
52. Avez-vous déjà suivi une formation sur la gestion de risque?	○	○	○	○

QUATRIÈME PARTIE : Questions complémentaires

1. Indiquez s'il vous plait si vous avez déjà reçu une formation en éthique (cours obligatoire, formation continue, etc.)

- Oui
- Non

2. Indiquez s'il vous plait si vous avez déjà reçu une formation en gestion de risque (cours, formation continue, etc.)

- Oui
- Non

16 Questions sociodémographiques

CINQUIÈME ET DERNIÈRE PARTIE : Renseignements généraux

1. Sexe

- Femme
- Homme

2. Âge

- Moins de 18 ans
- 18-29
- 30-39
- 40-49
- 50-59
- 60-69
- 70 ans et plus

3. Expérience en ingénierie

Depuis combien de temps exercez-vous la profession d'ingénieur?

- 2 ans ou moins
- 2 à 5 ans
- 5 à 10 ans
- 10 à 15 ans
- 15 à 20 ans
- 20 à 25 ans

- 25 à 30 ans
- 30 à 35 ans
- 35 à 40 ans
- 40 ans et plus

4. Expérience en gestion des risques industriels

À quelle fréquence, dans votre carrière professionnelle, avez-vous été appelé à participer à de la gestion des risques industriels?

- Jamais
- Rarement
- Parfois
- Souvent
- La plupart du temps
- En permanence

3. Indiquez s'il vous plait votre niveau actuel dans votre formation

- 1ère année
- 2ème année
- 3ème année
- 4ème année (Finissant)

5. Indiquez s'il vous plait le domaine de spécialisation de votre formation en ingénierie.

- Génie Aérospatial
- Génie Biomédical
- Génie Chimique / Génie des Procédés
- Génie Civil
- Génie Électrique
- Génie Géologique
- Génie Industriel
- Génie Informatique
- Génie Logiciel
- Génie des Matériaux
- Génie Mécanique
- Génie des Mines
- Génie Physique
- Autre. Précisez s'il vous plait

6. Indiquez s'il vous plait votre type de poste

- Étudiant cycle supérieur ou chercheur post-doc
- Professeur universitaire
- Cadre
- Cadre supérieur(e)
- Haute direction
- Personnel administratif
- Personnel technique/ Métiers
- Professionnel(le)
- Travailleur de la production
- Autre. Précisez s'il vous plait

7. Indiquez s'il vous plait dans quel secteur d'activité oeuvre votre organisation.

- Administration publique
- Aéronautique
- Arts, spectacle et Loisir
- Automobile
- Commerce de gros ou de détails

- Enseignement et/ou recherche en génie
- Enseignement et/ou recherche en sciences administratives, économiques et sociales
- Ferroviaire
- Finance et assurance
- Gestion des ressources (eau, énergie, etc.) et des déchets
- Industrie minière
- Naval
- Production d'énergie renouvelable (éolien, solaire, etc.)
- Production de gaz industriels
- Services immobilier ou de transactions immobiliaires
- Secteur des énergies fossiles (gaz, pétrole, nucléaire)
- Secteur de la santé
- Transport (routier, ferroviaire, maritime, aérien)
- Technologies de l'information
- Autre. Précisez s'il vous plait

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Bravo! Vous avez terminé de répondre au questionnaire!

L'équipe de recherche vous remercie de votre participation!

Vous pouvez dès à présent quitter ce questionnaire en fermant l'onglet de votre navigateur