

Ethical Risk Management Education in Engineering: A Systematic Review

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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 that specialize 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 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

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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

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 management¹ should thus be included in any engineer's education, as suggested by the Canadian Council of Professional Engineers (Amyotte and 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 (Accreditation Board for Engineering and Technology—ABET 2016) and Canada (Engineers Canada Accreditation Board—ECAB 2015).

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 (Pauchant and Mitroff 1992, 1995; Pauchant et al. 2008; Crandall et al. 2013; Guntzburger and Pauchant 2014). 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 (Shrivastava 1987; Beck 1992), the over-confidence in rational calculus (Beck 1992; Pauchant and Mitroff 1992), the necessity to consider the complex organizational, historical and social context (Leveson 2004; Guntzburger and Pauchant 2014), the low consideration for weak signals (Brizon and Wybo 2009) or public perception (Herkert 1994), the limits of decomposition, modelling or determinism (Cilliers and Preiser 2010; Murphy et al. 2011) and objective judgments (Macpherson 2008; Downer 2014) are just a few, but relevant, examples.

¹ 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, administering, etc.). See Frosdick (1997) for an explanation of the difference between management of risk (risk analysis) and risk management.

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 Science, Technology and Society (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 and Denyer 2012). The next section explains in detail the methodology used for this systematic review.

Methodology

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

Table 1 List of selected journals with their impact factor and SJR index (2014—when available)

Title	Impact factor	SJR index
Advances in Engineering Education	—	0.23
American Journal of Engineering Education	—	—
Education for Chemical Engineers	—	0.31
Engineering Studies	0.5	0.38
Ethics and Education	—	0.22
European Journal of Engineering Education	—	0.42
Global Journal of Engineering Education	—	0.18
IEEE Transactions on Education	0.84	0.68
International Journal of Collaborative Engineering	—	—
International Journal of Continuing Engineering Education and LifeLong Learning	—	0.18
International Journal of Engineering Education	0.58	0.31
International Journal of Engineering Pedagogy	—	—
International Journal of Engineering, Social Justice and Peace	—	—
International Journal of Quality Assurance in Engineering and Technology Education	—	—
International Journal of Service Learning in Engineering	—	—
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	—	—
World Transactions on Engineering and Technology Education	—	0.19

impact factor (Institute for Scientific Information), SCImago Journal Ranking (SJR), h-index (Google Scholar)² 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 was 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 1 regroups the sample of the 21

² The impact factor 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).

journals selected for this systematic review. It shows their impact factor and SJR index when available.

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 and 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 and 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 2 regroups the search strategies used to identify articles in each category: 1—main focus on risk management, 2—main focus on ethics, 3—

Table 2 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]

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.

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 papers³ 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 3. References for these articles are presented in Tables 5 and 6 within “Appendix”.

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 3, 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 a prime focus on risk management and a coupling with ethics and 2—articles with a prime focus on ethics and a coupling with risk management.

³ 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.).

Table 3 Number of article for each category in engineering education and each selected journals

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	1	0	0	0	0
American Journal of Engineering Education	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	8	27	0	3	16
Global Journal of Engineering Education	2	4	0	0	2
IEEE Transactions on Education	7	9	0	1	4
International Journal of Collaborative Engineering	0	0	0	0	0
International Journal of Continuing Engineering Education and LifeLong Learning	1	1	0	0	0
International Journal of Engineering Education	4	20	0	0	2
International Journal of Engineering Pedagogy	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	0	0	0	0	0
International Journal of Service Learning in Engineering	1	1	0	1	0
Journal of Business Ethics Education	0	0	0	0	0
Journal of Engineering Education	3	28	0	3	22

Table 3 continued

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
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	0	0	0	0	0
World Transactions on Engineering and Technology Education	7	1	0	2	1
Total	46	175	0	20	115

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 ECAB, 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 will lead to a discussion of these findings.

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.

Descriptive Findings

Quantitative Results

Table 3 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.

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 (*Journal of Engineering Education*—JEE, *Journal of Professional Issues in Engineering Education and Practice*—JPIEEP, *International Journal of Engineering Education*—IJEE, and *European Journal of Engineering Education*—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 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; Perrin and Laurent 2008; Petersen et al. 2008; Langdon et al. 2010) and the development of specialized courses using multidisciplinary approaches (McKnight et al. 1996; Hashash et al. 2012). Pedagogical methods are also proposed such as case studies (Dembe 1996; Bignell 1999; Shallcross 2013a), concept maps (Shallcross 2013b, c), 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, National Society of Professional Engineers—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, Fig. 1 shows the evolution of the number of published articles for each identified category, from 1980 to March 2016.

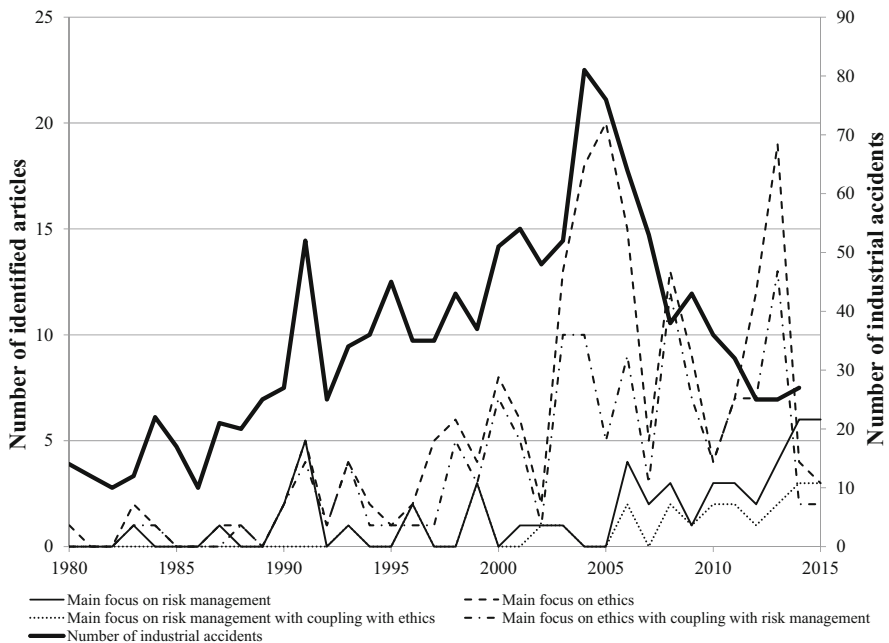


Fig. 1 Number of article for each identified article category from 1978 to 2015 and number of industrial accidents for the same period (EM-DAT Database, Guha-Sapir et al., 2015) (secondary axis)

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 1 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.⁴ 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 (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; Pauchant and Mitroff 1992; Leveson 2004; Cilliers and Preiser 2010; Guntzburger and Pauchant 2014).

⁴ Those data were gathered from the EM-DAT database, available online (see Guha-Sapir et al. 2015).

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.

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 a 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 and Laurent 2008, p. 89). Moreover, they show Hill’s model (2003) illustrating a safety ethic which “provides the opportunity to strive for 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

Table 4 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

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 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 a scenario, a 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 (Pantazidou and Nair 1999; Russell and Stouffer 2003; Barry and Ohland 2009). 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. Kiepas 1997; Loui 2005; Sinha et al. 2007; Colby and Sullivan 2008; Jonassen and Cho 2011; Lau et al. 2013).

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 3-h 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 the addressing of 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 (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-Kastenberget 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 (2008) argues that preventive ethics is mostly based on negative rules which are not suitable for a 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.

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 and 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 a level of complexity. Furthermore, considering that engineers, because of their training, may eventually neglect or depreciate multiple dimensions (emotional, social, etc.), perspectives or approaches (O'Brien et al. 2003; Downey 2005; Richter and 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, Leveson 2004; Leveson et al. 2009; Aven and Zio 2011), 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 and Preiser 2010; Woermann 2013) and reflections on acceptable evidences (see Mayo and 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, for risk management and risk acceptance are clearly value-laden (Patenaude et al. 2014). 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 and Aven 2008). None of the literature analyzed here has explicitly addressed this question. We believe that these issues 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.

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

See Tables 5 and 6.

Table 5 References of papers focusing on risk management issues and coupling ethical concepts*Anecdotal or illustrative*

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