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Engineering

AN OVERVIEW OF PAST AND CURRENT ENGINEERING ETHICS RESEARCH TRENDS

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ABSTRACT:
THIS ARTICLE PRESENTS AN EXPLORATIVE LITERATURE RESEARCH OF THE PAST AND CURRENT TREND OF ENGINEERING ETHICS RESEARCH AND ENGINEERING ETHICS EDUCATION RESEARCH. MAJOR SUBTHEMES ABOUT ENGINEERING AND ETHICS ARE IDENTIFIED AND THE MOST INFLUENTIAL ARTICLES IN THIS FIELD ARE CONSIDERED. THE DISCUSSIONS ON RESEARCH TRENDS ARE BASED ON INFORMATION GATHERED USING BOTH QUANTITATIVE AND QUALITATIVE METHODS. RESEARCH DATA SHOWED AN INCREASING INTEREST IN APPROACHING ETHICS FROM THE ENGINEERING PERSPECTIVE. THE PURPOSE OF THIS ANALYSIS IS RELATED TO THE NECESSITY OF INCORPORATING ETHICAL ASPECTS IN ENGINEERING STUDENTS EDUCATION FOR MAKING THEM AWARE AND RESPONSIBLE OF THE IMPLICATIONS OF MODERN TECHNOLOGIES.

KEY WORDS: ETHICS, LITERATURE REVIEW, ENGINEERING, RESEARCH, EDUCATION

INTRODUCTION

Together with the steps taken by mankind on the path of technological development, new ethical dilemmas arose about the implications of using these technologies. At the forefront of the technological development, engineers are the ones shaping technology and having an active role in guiding the ethics behind the technology. Several codes of ethics or ethical guides for the engineering profession have been developed in time and in different countries[3], however internalizing their principles is no one stop shop for (future) engineers. On the other hand, the engineering field is so vast and intertwined with numerous other fields of research that it can hardly be called one single field anymore. Thus, one single code of ethics for the engineer cannot possibly be comprehensive for all contexts. For example, passive and active responsibility, engineers versus

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[3] The Royal Academy of Engineering; *Engineering ethics in practice: a guide for engineers*, London. 2011. Available at: www.raeng.org.uk/ethicsinpractice

managers and whistle-blowing are general themes discussed in most textbooks on engineering ethics[4].

Engineering ethics is a subject of interest to us from the point of view of the educator needing to incorporate ethical aspects in the educational paths of engineering students and raising ethical awareness of the students while educating them about a certain technology. Students must be taught to evaluate the risks and the implications of developing or using different scientific approaches, technologies or information over peoples' life, economy, business practice, etc. For instance, the ethical aspects related to conducting experiments, performing tests and using their results, to legal issues on using digital data, safety aspects, intellectual property rights[5], etc. should all be taken into account by engineers as technology developers. Therefore, in order to identify the main issues already or to be included in the educational development of engineering students, an explorative literature research of the past and current state of ethics research and ethics education research was conducted. This article presents the first findings of this explorative literature research. Used methods and findings are detailed in the following.

METHOD AND FINDINGS

The interest in conducting this explorative literature review about engineering and ethics was twofold: first to map the research field concerning engineering and ethics based on identification of research subthemes, and second to explore in particular the subtheme of education, meaning those articles addressing the issue of ethics in the context of the engineering education. As data source, Web of Science Clarivate Analytics(C) (WoS) database was mainly used for the quantitative and qualitative analyses. A second resource source was the Scopus(C) database, but this was used only in the first instance quantitative analysis and served the purpose of validating the main quantitative trends. Data was extracted from Web of Science Clarivate Analytic(C) (WoS) and Scopus(C) in August 2018 and it was valid at this date. The explorative analysis contained three steps, described in the following.

In the first step, a search in WoS and Scopus was run for collecting necessary data. In WoS, a first search on ethics and engineering in the title (TI) or in the topics (TS) of the articles (TI=(ethics) OR TS=(ethics) AND TS=(engineering) OR TI=(engineering)) resulted in 251,939 items. These results were refined with search string in the advanced search option from WoS: (TI=(ethical) OR TS=(ethics)) AND (TS=(engineering) OR TI=(engineering)), thus obtaining 2536 results. In this step the instruments available in WoS were used to look at the articles depending on the number of citations, affiliation and geographical interest. In this phase we also compared these aspects with the data available in Scopus.

Based on the number of published articles about ethics and engineering, an ascending trend was observed (as shown in Figure 1) demonstrating the growing interest of researchers in different ethical aspects of the engineering field. As technology evolves it brings new ethical dilemmas that both society and scientists must face and solve.

[4] Van de Poel, Ibo; Royakkers, Lamber; *Ethics, Technology and Engineering. An Introduction*, Wiley-Blackwell, 2011.
[5] Daly, Angela, *Socio-Legal Aspects of the 3D Printing Revolution*, ISBN 978-1-137-51555-1 Springer, 2016

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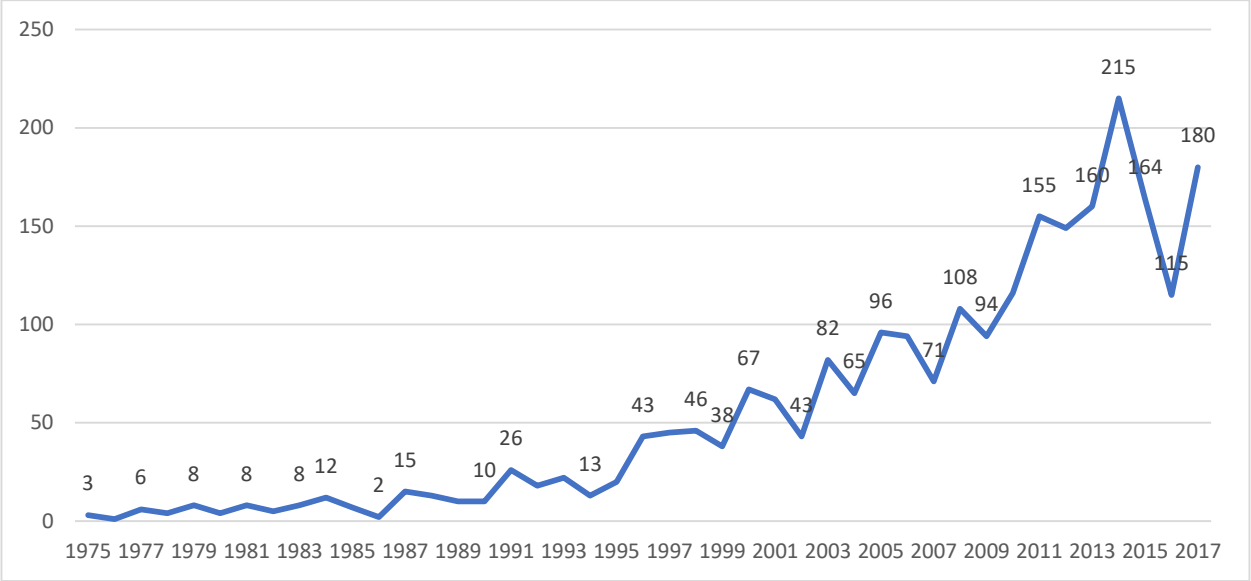

Figure 1. Trend for number of articles in the Web of Science Clarivate Analytics database containing Ethics in the title or the topic and Engineering in the title of the topic. Time frame 1975-2017

Using the search options from the Web of Science Clarivate Analytics database, additional interesting information were found. The most prolific writer, with 25 articles is Michael Davis, whose most cited article (67 citations) is *Thinking like an engineer - the place of a code of ethics in the practice of a profession*. The Journal that has published the most articles on the subject is *Science and Engineering Ethics* (with 290 results) with an impact factor of 1.859 in 2017, in Q1 in the Ethics section and in Q2 in Engineering multidisciplinary.

Almost half of the results (1229) have USA as country/region registered in the Web of Science Clarivate Analytics. However, the organization most mentioned as affiliation of authors is Delft University of Technology (Netherlands), followed by Purdue University (USA). This could show the high localised interest in the subject of engineering ethics of researchers from Delft University of Technology and the spread interest of US researchers, resulting in US researchers publishing from many US universities/research institutions, etc.

Refining the 2536 paper titles based on the topic "Education", as it is classified in WoS, a list of 754 results was obtained. There is a similar ascending trend for the published papers regarding ethics engineering education, peaking between 2013 and 2015. The average number of citations for the articles in this category is 4. If we look at the category engineering ethics, there are 580 articles registered in this WoS category.

In the Scopus database, when looking for "ethics" AND "Engineering" in title, abstract and keywords, 7738 documents were generated, with the number of articles per year increasing and peaking in 2017 (Figure 2). The same trend was found also in WoS Clarivate Analytics. Here we find the same name as being the most prolific author - Davis, Michael. The same article as in Clarivate is the most cited one *The ABET "Professional skills" - Can they be taught? Can they be assessed?*[6]. The first 2 affiliation institutions have switched places, with Purdue University ranking

[6] Shuman, LJ.; Besterfield-Sacre, M.; McGourty, J.; The ABET "Professional skills" - Can they be taught? Can they be assessed? Journal of Engineering Education. Volume: 94, Pages:41-55, 2005.

first and Delft University of Technology second, with the USA still being the most mentioned geographical area.

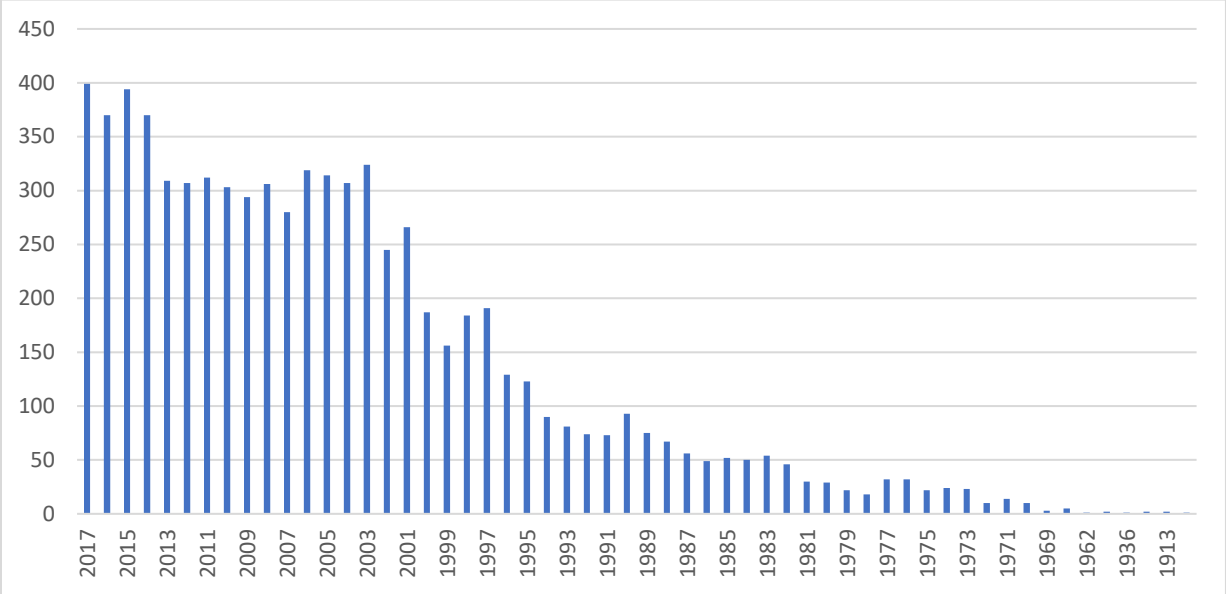

Figure 2. Trend for articles in the SCOPUS database containing Ethics and Engineering* in the title, abstract or keywords. Time frame 1909-2017*

In the second step of the analysis, the results were exported in a spreadsheet format, which contained 2493 cases. Duplicate cases were searched for exclusion. The automated function found 59 such cases. However, after a first analysis, not all of these resulted in actual duplicate cases, as some articles had the same title but different authors and publication source. The second step contained the main qualitative analysis of the articles. We classified articles in different subthemes based on their title. Where the title was not conclusive, we looked at the summary available in WoS. If no summary was available or if from the summary it resulted that the article was not mainly about engineering and ethics, the article was removed from the analysis.

We first looked at the all the articles and classified them in subthemes. The largest identified subthemes (and their classification algorithm) are the following:

- Education: students, education, curriculum, teaching, training, classroom, learning, university etc.
- Artificial Intelligence (AI): Artificial Intelligence, robots, Self-Driving/autonomous vehicles, intelligent machines etc.
- Bioethics/bioengineering: GM food, biology etc.
- Medicine: genetic*[7], tissue, clinical, stem cells, hospital, pharmaceutical, mitochondrial, embryo, vaccine etc.
- General: ethics/ethical + engineers/engineering (+ code of/framework), (social) responsibility*[7], moral, challenges etc.
- Animal welfare: animal (and examples of) etc.

[7] *and derivates of

- Environment: sustainable*[7], renewable, climate, solar, water, green etc.
- Case studies.

By far the largest subtheme is that which was labelled Education. The second largest subtheme is that which was labelled General, containing articles mostly regarding codes of ethics or discussions of ethical dilemmas of engineers. One of the most controversial and debated ethical aspect of engineering products is found at the crossroad between engineering and the medical field. For instance, the implications of using Additive Manufacturing technology in medical applications (3D printing of biomaterials, organs, etc.) represent a new subject of debate in the field[8;9]. Another discussed subject around the ethics of engineering is found in connection with AI. Here, questions about how to incorporate ethical decisions making in a machine has been both the subject of scientific research and of science fiction.

We also looked at the Web of Science Categories that these articles were classified under. In WoS, one article can be classified under more than one category, and this is the case of the majority of the articles we looked at about engineering and ethics. It was seen that the existing classification overlaps the category identified as the largest one – Education, but it is divided into two subthemes: Education scientific disciplines and Education educational research. The WoS Categories are narrower than our classification. For example, the identified "Medical" subtheme is divided in: Medical ethics and Medicine research experimental.

In the first 15 years of published research on engineering and ethics, in the 1975-1990 timeframe, the titles of the articles suggest the exploration of general, broader aspects of ethics in the engineering field, when compared to the titles from the third timeframe. The titles of the published articles are shorter: "*Engineering Ethics*", "*Engineering and Ethics*", "*Morals and Engineering Ethics*", "*Ethical Engineering*", "*The Search for Engineering Ethics*" etc. In the 2000-2017 timeframe, articles have become more focused, with many subdomains specific case studies, prevailing subthemes relating to genetic research or AI research.

In the third step, we looked at the first 10 most cited papers from WoS based on the search terms ethics and engineering in the title or the topic of the article and we analyzed on how they connect with the subthemes identified in the previous step. In this third step we also used CiteSpaceIII app for looking at the citations trends found in our data.

The 10 most cited articles in WoS based on the search terms ethics and engineering in the title or the topic of the article are presented in Table 1. They show the wide range of subthemes

[8] Gilbert, F, O'Connell; CD; Mladenovska, T; Dodds, S; Print me an organ? Ethical and regulatory issues emerging from 3D Bioprinting in medicine, Science and Engineering Ethics, vol. 24, issue 1, Pages 73-91, 2018
[9] Neely, E; The risks of revolution: ethical dilemmas in 3D printing from a US perspective, Science and Engineering Ethics, vol. 22, issue 5, DOI 10.1007/s11948-015-9707-4, 2016

that are found under engineering and ethics, from education[10], medicine/health[11;12;13;14], environmental aspects[15], and behaviour sciences[16].

The top cited article[17] analyses several engineering curricula, advocating the integration of professional (soft) skills in the education trajectory of engineering students. Among these skills the authors mention communication, teamwork, and the ability to recognize and resolve ethical dilemmas[17]. The authors show that effective educational activities should be based on fidelity (to the actual future work environment) and on complexity (which includes task interdependency and cognitive effort)[17]. Following a meta-analysis of different ethics educational programs, the effectiveness of case based and interactive ethics education has been underlined by[18] also, even if the authors draw a less positive conclusion about the success of ethics instruction, the results being characterized as rather "modest".

Regarding the other subthemes of the most cited articles, in [19] a comprehensive approach on geoengineering is presented, including some of its ethical implications. In the medicine category we have found articles [20;21;22] dedicated to genetics and genetic engineering. General ethical aspects of technology and engineering and design ethics are discussed in [23]. In Harding et al.[24] we found a comparative research on professional and academic dishonesty among engineering students that we classified under the theme behaviour sciences.

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[10] Shuman, LJ.; Besterfield-Sacre, M.; McGourty, J.; *The ABET "Professional skills" - Can they be taught? Can they be assessed?* Journal of Engineering Education. Volume: 94, Pages:41-55, 2005.

[11] Frewer, LJ; Howard, C; Shepherd, R. *Public concerns in the United Kingdom about general and specific applications of genetic engineering: Risk, benefit, and ethics.* Science Technology & Human Values, 1997

[12] Bhargava, Saurabh; Patterson, Jacob M.; Inman, Richard D.; MacNeil, Sheila; Chapple, Christopher R. *Tissue-engineered buccal mucosa urethroplasty - Clinical outcomes*. European Urology, 2008

[13] Sadler, TD; Zeidler, DL. *The significance of content knowledge for informal reasoning regarding socioscientific issues: Applying genetics knowledge to genetic engineering issues*. Science Education, 2005

[14] Schilling, AF; Linhart, W; Filke, S; Gebauer, M; Schinke, T; Rueger, JM; Amling, M. *Resorbability of bone substitute biomaterials by human osteoclasts*. Biomaterials, 2004

[15] Keith, DW. *Geoengineering the climate: History and prospect*. Annual Review Of Energy And The Environment, 2000

[16] Harding, TS; Carpenter, DD; Finelli, CJ; Passow, HJ. *Does academic dishonesty relate to unethical behavior in professional practice? An exploratory study*. Science And Engineering Ethics, 2004

[17] Shuman, LJ.; Besterfield-Sacre, M.; McGourty, J.; *The ABET "Professional skills" - Can they be taught? Can they be assessed?* Journal of Engineering Education. Volume: 94, Pages:41-55, 2005.

[18] Antes, Alison L.; Murphy, Stephen T.; Waples, Ethan P. Mumford, Michael D., Brown, Ryan P., Connelly, Shane & Devenport, Lynn D., *A Meta-Analysis of Ethics Instruction Effectiveness in the Sciences*, Ethics & Behavior, 19:5, 379-402, 2009.

[19] Keith, DW.; *Geoengineering the climate: History and prospect*. Annual Review Of Energy And The Environment, 2000

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[23] Verbeek, PP.; *Materializing morality - Design ethics and technological mediation*. Science Technology & Human Values, 2006

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Author(s)	Title	Journal/ Publication name	Publ. year	Nr. of citations in WoS
Shuman, LJ; Besterfield-Sacre, M; McGourty, J	The ABET "Professional skills" - Can they be taught? Can they be assessed?	Journal of Engineering Education	2005	368
Keith, DW	Geoengineering the climate: History and prospect	Annual Review of Energy and the Environment	2000	249
Frewer, LJ; Howard, C; Shepherd, R	Public concerns in the United Kingdom about general and specific applications of genetic engineering: Risk, benefit, and ethics	Science Technology & Human Values	1997	167
Verbeek, PP	Materializing morality - Design ethics and technological mediation	Science Technology & Human Values	2006	133
Bhargava, S.; Patterson, J.M.; Inman, R.D.; MacNeil, S.; Chapple, C.R.	Tissue-engineered buccal mucosa urethroplasty - Clinical outcomes	European Urology	2008	120
Sadler, TD; Zeidler, DL	The significance of content knowledge for informal reasoning regarding socioscientific issues: Applying genetics knowledge to genetic engineering issues	Science Education	2005	119
Schilling, A.F; Linhart, W; Filke, S; Gebauer, M; Schinke, T; Rueger, J.M; Amling, M	Resorbability of bone substitute biomaterials by human osteoclasts	Biomaterials	2004	111
Sparrow, R.; Sparrow, L.	In the hands of machines? The future of aged care	Minds and Machines	2006	110
Harding, T.S; Carpenter, D.D; Finelli, C.J; Passow, H.J	Does academic dishonesty relate to unethical behavior in professional practice? An exploratory study	Science and Engineering Ethics	2004	108
Roco, M.C; Bainbridge, WS	Societal implications of nanoscience and nanotechnology: Maximizing human benefit	Journal of Nanoparticle Research	2005	102

In this step of our exploratory researched we also used CiteSpaceIII, a free tool used for visualization of a knowledge domain based on relevant publications [25; 26; 27.] Based on the files exported from WoS, we looked at the citation bursts in the 1996 - 2018 time period. The results are presented in Figure 3.

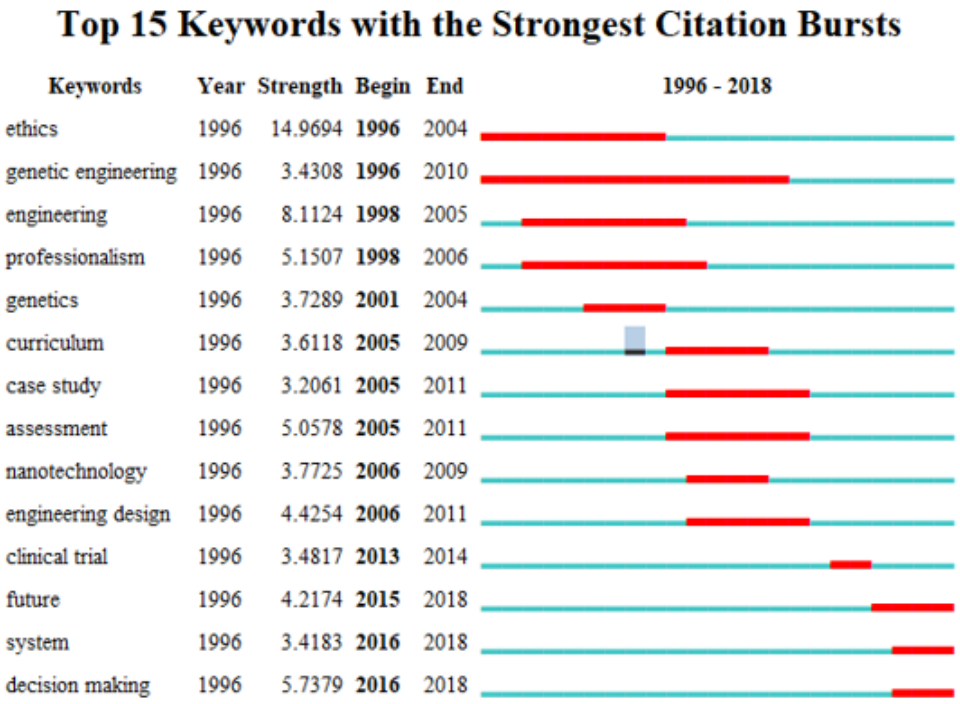

Figure 3. Trend for citation bursts using CiteSpace on WoS indexed articles about engineering and ethics

We see again that the genetics is one of the most discussed themes, the educational theme, represented here under curriculum, being also of high interest. As a matter of fact, how to incorporate ethics into engineering curriculum is a shared and long-term matter of scientific inquiry. During time, new aspects and subjects related to engineering ethics were added to these curriculums referring, for instance, to data ethics, digital ethics, robotics and artificial intelligence, drones, environment and sustainability, genetics, bioprinting etc. The emerging technologies are raising new ethical and regulatory issues, most of them representing real challenges for society.

CONCLUSIONS AND FURTHER WORK

[25] Chen, Chaomei. *Searching for intellectual turning points: Progressive knowledge domain visualization*. Proceedings of the National Academy of Sciences of the United States of America, 101, 5303–5310, 2004.
[26] Chen, Chaomei**.** CiteSpace II: *Detecting and visualizing emerging trends and transient patterns in scientific literature*. Journal of the American Society for information Science and Technology, 57, 359–377, 2006.
[27]Chen, Chaomei. *The CiteSpace Manual.* 2014. Available at:
http://cluster.ischool.drexel.edu/~cchen/citespace/CiteSpaceManual.pdf

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The ethical questions in the engineering field have evolved in light of the technological developments. The interest in engineering ethics research and engineering ethics education research has been constantly growing and scholars continue to study the most effective ways of incorporating ethics training in the educational engineering programs. There are several ethical codes of conduct for the engineering profession, but our class experience has shown that these are for the most part unknown by students. In this article we looked at the major subthemes that could be identified in research about engineering and ethics. We found that the ways of how to include ethics in the education of future engineers is one of the major interests of scholars in this field. Our future work includes a systematic review of papers about the way ethical principles and critical thinking about ethical dilemmas can be included in the engineering curriculum and the effective ways they can be internalised by students.

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