Integral Engineering Education: an approach to implementation

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INTRODUCTION

In the last decades, engineering education has gained attention with the NAS report on the state of technology education [4] and several follow-up reports [14], [20]. The trend is that engineers need a broader profile. It is considered short-sighted and

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ineffectual to just produce more engineers without also increasing the quality of engineering education [9]. For that reason, the engineer needs to become communicative, entrepreneurial, ecologically aware and he[2] should show leadership in guiding society, the economy and nations to wealth and welfare.

Is it sufficient then to expand the curriculum with non-technical skills? Engineering is quintessentially a human endeavor: it builds artifacts that influence behavior of individuals and of groups. In that respect, an engineer should be aware of what it means to be human, which is as wide as “literature, history, philosophy, psychology, religion, and economics, among other fields” [9]. To build such an engineering profile, this paper moves beyond the goals of many contemporary reform proposals. We propose a change in world view for the engineer, a shift of consciousness that positions him in the world that he is engineering. Moving away from an engineer-as-a-subject, the engineer has a much more involved role in the world than before.

1. TECHNOLOGICAL ADVANCES, IMPACT ON ENGINEERING EDUCATION

Technology is developing faster than ever and there are no signs of it slowing down. New fields in engineering emerge on a regular basis. This has an impact on the relationship between core engineering disciplines and newer ones: “New branches, such as food engineering, pharmaceutical engineering, biochemical engineering, environmental engineering, fire engineering, etc. threaten … to disrupt or dilute the basic curriculum” [8]. Even for these new fields, R&D results in specialization. Increasingly advanced technology and specialization feeds the outside impression that technology education results in masses of narrow-minded specialists.[3] This specialization also impacts the relations with more fundamental disciplines. A computer department may re-evaluate if fundamental mathematics are needed when most students never encounter advanced mathematics after graduation. They may consider organizing a specialized course on discrete and applied mathematics. While this approach guarantees that the subject matter will be applicable to the field at hand, the risk exists that links with fundamental science are severed and that relevant evolutions in those fields are not transferred to newer engineering branches.

2. GENERAL TREND IN ENGINEERING EDUCATION REFORM

Most contemporary reforms take the view that engineering requires a wider approach than a purely scientific one[4]. To define the wider profile, a common approach has three steps: painting a picture of the desired profile, identifying attributes or characteristics of this profile, then adapting the curriculum to match this profile.

The CDIO™ Initiative (Conceive-Design-Implement-Operate) is a well-documented example of a contemporary reform. It was originally conceived at MIT in the late 1990s. The Initiative was founded in collaboration with Chalmers University of Technology, Linköping University and the Royal Institute of Technology. It describes the need for reform as follows:

> *The task of higher education is to educate students to become effective modern engineers – able to participate and eventually to lead in aspects of conceiving,*

[2] Note that this article refers to the education of every possible engineer. For easy reading, we use “he” as a convention when referring to an engineer in general, without any assumptions on the individuality.

[3] Works discussing the problems of overspecialization go back at least half a century [17]. It is also the reason for many initiatives in engineering reform, e.g.: “Common (…) was an implicit criticism of current engineering education for prioritizing the teaching of theory(…)” [5]

[4] This breaks with the post-war trend towards more scientific engineering, ref [5] for a good overview.

> *designing, implementing, and operating systems, products, processes, and projects. To do this, students must be technically expert, socially responsible, and inclined to innovate. [5]*

To achieve this, CDIO takes the approach described above: painting a profile, identifying attributes, then modifying the curriculum to achieve the goal:

> *Any approach to improving engineering education must address two central questions:*
>
> - *What is the full set of knowledge, skills, and attitudes that engineering students should possess as they leave the university, and at what level of proficiency?*
> - *How can we do better at ensuring that students learn these skills ? [5]*

Co-op (cooperative and work-integrated education) is another popular contemporary reform. Co-op combines “classroom studies with professional work experience in a field related to your education and career goals” [30]. The goals include hands-on experience, application of classroom knowledge, developing a number of soft skills and building a strong résumé by getting relevant work experience.[28] Implicitly, this paints a picture of an ideal engineer: instead of being theoretically minded, he has the skills needed for a real-life work context and experience in applying these skills. Other reforms also follow the pattern of identifying required “attributes”.[5]

Attributes exist in three types: knowledge, skills and attitudes. All three are techniques: you learn, repeat and perfect them. Thus, engineering education consists of studying (knowledge) and practicing techniques (skill). Attitudes are an acquired aspect of behavior and can also be learned, practiced and perfected. [6] When one notices an unhelpful attitude, one can practice a new attitude. For that reason, this paper collectively refers to all types of attributes as “technique”. While this certainly simplifies a complex reality, it is useful to compare the acquired aspects of an engineer’s personality with the non-acquired awareness that this paper puts forward. Most contemporary reforms thus add more acquired technique to the curriculum. While this expansion the scope of is necessary to improve the profile of an engineer, it cannot be denied that it magnifies the problem. On one side, technological expansion puts a strain on the curriculum. On the other side, additional technique for a desired wider profile of engineers increases this strain. It becomes an increasingly tough balancing act to give each part its deserved place. Worst case, this can turn the curriculum into a battlefield as educators and the proponents of technology vie for a prominent part of the proverbial pie.

3. INTEGRAL ENGINEERING EDUCATION: ENGINEERING AS A HUMAN ENDEAVOR

On a more positive note, the advances in technology offer incredible opportunities for the progress of humanity as a whole: “Science and technology have progressed to the point where what we build is only constrained by the limits of our imaginations” [23]. The challenge is to train engineers who can imagine ways to improve our human condition. In this sense, engineering is an act of creation: “What I wish to propose are the propositions that creation in Art and creation in Engineering have

[5]Several studies have been published that are preparations for reform and identify the attributes of engineers. For example, see the list of attributes in [21]. [16] discusses 172 skills, knowledge descriptors and experiences.

[6]Attitudes form an important part of post-war psychological research. The viewpoint of this paper is simplified for the sake of argument. For more detailed descriptions on acquiring attitudes, see for example [7] and [22].

much in common" [24].[7] Looking at visual arts, tools and techniques tend to become the focus of discussion when the art is more technological.[8] As engineering is an extreme form of a technology supported creative act, it reaches the point where the attention for the technological side can eclipse all other aspects.[9]

Instead of focusing on attributes of an engineer's profile, this paper therefore proposes to take a look at the role of the engineer. Hansen and Froelich [11] define technology as the means by which people mediate between nature and themselves. Hansen later expands this view:

> *From this foundation an important feature of technology becomes apparent: technology is very much a cultural phenomenon. [10]*

Indeed, an engineer is a part of the human culture. He is a mediator between nature and culture. Using nature as a resource, he shapes his culture. At the same time, his effect on culture reflects back on nature. This introduces paradoxes into the concept of engineering and the engineer. The first paradox is: when culture reshapes the nature that the engineer uses as a resource, how can we still consider nature to be separate from culture? It seems that culture and nature belong together as a yin-and-yang, inseparable opposites of the same coin.[10]

Furthermore, reality itself turns out to be inherently paradoxical as well. In physics, the more we explore the smallest particles of matter, the more they turn out to be wave-like [1]. And in mathematics, the harder Whitehead and Russell tried to banish paradox, the more paradox appeared in their work.[11] Engineering as a process is paradoxical as well: the more certain we are that something works, the higher the stakes of failure. If project A is assumed to have a high certainty of success, new assumptions and projects will be built on top the core assumption that project A will succeed. If project A would fail, the impact is much larger than with projects that are not assumed to succeed.[12] This paradox is illustrated in *Fig. 1*.

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[7]Shuster agrees that innovation is crucial, but being creative, it is outside of the typical curriculum and the public image of engineering: "Contrary to the misconceptions (…), Engineering, Science, and Mathematics are not purely deductive disciplines. Innovation in these disciplines, certainly, is not. (…) The most important activity is *induction*, how we determine the things we wish to prove (or discover or design or invent) and how we are going to prove (or discover or design or invent) these things from observation, analogy, and the magical element we call intuition. Stated in other words, the most important part of research is not finding the solutions but finding the problems." [24].

[8]One needs only look at Internet forums on photography to notice that a large part of the discussion is about the equipment and the technical aspects, not about creative aspects. With less technological visual arts like painting or sculpture, it is much harder to discuss or measure the technical qualities or methods.

[9]Engineering itself nearly always produces the tools that it uses. This creates a feedback loop where the creation becomes the tool, thus enhancing the tools focus of engineering. In art, it is easier to get out of the technology focus by starting to use the tools as a means of creation instead of looking at them as a goal in themselves.

[10] Ken Wilber goes as far as to suggest that reality itself changes as humans, being part of nature, evolve. [31]

[11]Referring to [12], Smith and Berg describe how the effort to banish paradox from mathematics generated only more paradox: "But their (Whitehead and Russel, ed.) endeavor exposed numerous strange loops, showing that while we can think using one set of symbols, if we use these same symbols for thinking about our thinking, we find ourselves caught in a tangled hierarchy that creates remarkable confusion" [25].

[12] This is why the agile methodology refuses to work with large-scale projects. In some cases, agile companies go as far as to start up several alternative solutions to a problem in separate project teams, assuming that a project can fail. For more information about the agile way of working, refer to the Agile Manifesto [3].

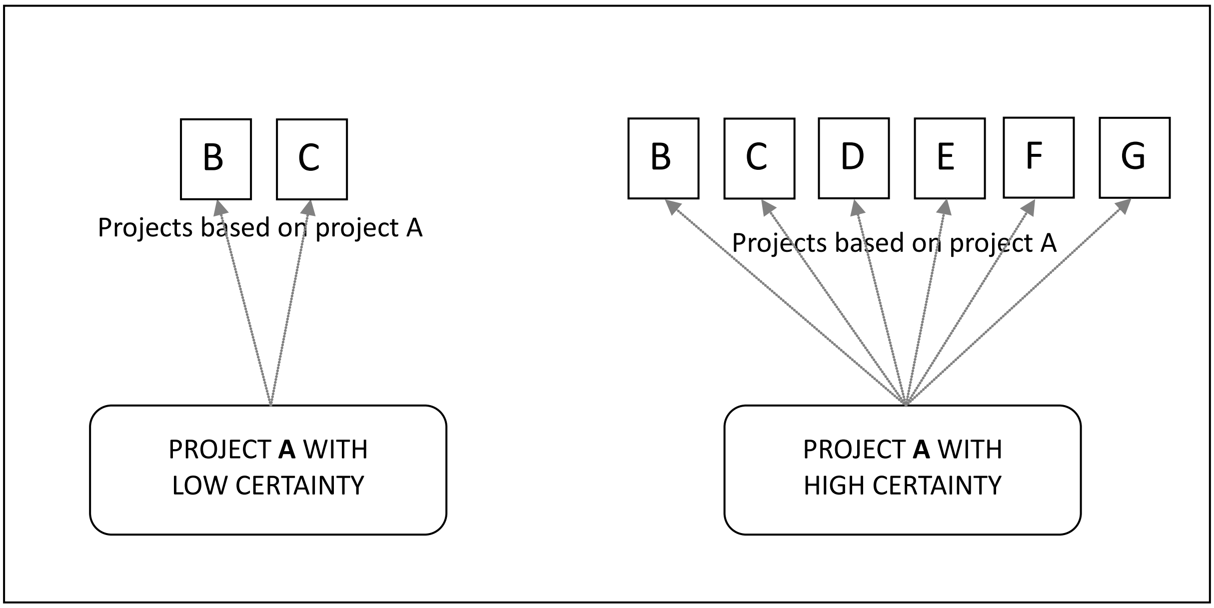

Fig. 1. More assumptions in case of high certainty

The more engineering tries to control certain aspects of reality, the more seems to come up that eludes control. Looking at himself, an engineer discovers that he is a collection of paradoxes. The brain, being enormously redundant and overlapping, is at the same time tremendously efficient.[13] Working in teams offers its own paradoxes.[14] Even existence as he experiences it offers its own paradoxes: the engineer is not separate from what he is working on, he is part of it. This can experimentally be discovered by introspection:

> *Bohm believes that the human mind, through centuries of conditioning, tends not to notice the inner paradoxes that have given rise to the outward confusion and disorder we are confronted with in our existence. The appropriate way of dealing with these difficulties may seem deceptively simple. In his view, all one has to do is to pause and create space. In this emptiness one can start to give serious and sustained attention to the paradoxical patterns that have come to dominate one's thinking and feeling. (…) In this way we have arrived at what has been termed the root paradox. If one conceives of one's environment as an extension of oneself, the process of thinking has become inseparable from the object of thought. It becomes impossible to establish whether the paradox concerned resides in culture or in nature, whether it belongs to the subject or the object, whether it stems from one's experience or from the environment, whether it applies to the one or the all." [6].*

Paradoxically, the change of world view described here is not something that can be acquired: the conditions can be set for the change to occur, but when the change happens, it is spontaneous.[15] To allow this to occur, we should move beyond a technique based reform and reclaim the engineer as an inherently creative human. This approach is a radical shift away from the traditional idea of an engineer. Instead

[13] See e.g. [2]

[14] "The most basic dilemma for individuals in groups is connected to the inner ambivalences generated by group membership. Each individual, on joining a group, experiences some ambivalence that stems from the *simultaneous* wish to be both "a part" of the group and "apart" from the group." [25]

[15] Other studies also indicate non-acquired factors play an important role in the definition of a future engineer: ethical reflection [26] or inquisitiveness, based on Aristotelian phronesis, e.g. [15] and [19]. We consider these factors to be important, but to be a consequence of the change in world view as proposed in this paper.

of being a subject who masters his objects using technique, he now makes up an integral part of the world and, in his role as a bridge between nature and culture, he opens up the possibilities that are inherently present in the situation. Because he is an open and unlimited part of the whole, he is open to any possible outcome, including those that move beyond historical techniques or even technology.

4. CASE STUDY

Group T – International University College Leuven was founded in 1888. After consolidating the main engineering disciplines, the college started internationalizing and focusing on education reforms from around the middle of the 1990s. Out of a humanist vision and real-life education experience, Group T built up a radical world view of an engineer in his world. The result has been a success, both in the feedback of stakeholders as well as in the growth of the school. Changing the world view of students is a process that takes time and that cannot be forced. For that reason, the efforts are spread out over the entire period of study. Starting from the bachelor studies, the new world view permeates the curriculum. The crowning work is the two year master path that gives the students the context to work in an end-to-end project, managing technical as well as marketing and financial aspects of a large project.

The college offers a context that forces students to reconsider several of their basic assumptions about engineering and education. The open structure of the college building reflects the connected nature of an engineer and offers a sort of transparency atypical of an educational institute. The highly international population of students and staff also challenges the student. Group discussions and projects with Europeans, Chinese, Indians and Ethiopians confront students not only with the subject matter, but also with different points of view. The teaching staff therefore find themselves in a dual position where they not only provide information but also guide conversations, coach individuals and groups, and indicate that there is frequently more than one correct answer. In evaluations, students indicate they appreciate this approach and point out high-level and humanist topics they want to work on, rather than focusing only on the more technical skills [13].

Engineering For The Real World

This course focuses on Group T's vision that engineers develop people. Students work on cases that illustrate the mutual impact of technology and society. They learn how technology evolves, and which factors - technological and non-technological - they have to take into account to develop a successful technological product. In this course a ‘successful’ solution is adopted by society and has the capability of inducing the foreseen change. The course has the following two parts:

- **Evolution of products**: The students take a look at a specific technological product. They study how its introduction impacted the world and how the world has reacted by changing the product. Initial product development is studied through questions around the goal of the product, the origin of the idea, the properties and target audience of the product. Using the model of social construction of technology, the product’s life cycle is further analyzed: did the product change society, did this result in a change of the product, how did the product and target group evolve ?

- **Larger scale case studies**: The goal of the second assignment is to ‘solve’ a specific problem in society. This solution can contain a technological component, but also non-technological aspects can and should be taken into account. In case technology is involved, it should be effectively designed/applied. Therefore students should rely on theories of adoption of technology, drivers of behavioral change and systems thinking. Examples of problems include childhood obesity, or violence in public transportation. The evaluation is based not only on the problem the student worked on, but also on his understanding of the problems and proposed solutions presented by the other students.

Beyond Engineering

The course Beyond Engineering looks at sustainability from four angles:

- **Technological**: The means to implement a specific aspect of sustainability are studied in-depth. As engineering is inherently a technological study, this aspect is an important part. Are there risks involved with the chosen technology? Is one technological approach better than another because it is simpler, more elegant, more proven, or for other reasons?
- **Economical**: Aside from technological feasibility, the solution must also be affordable and long-term viable. Where can money be found to fund the solution? What cost savings will occur and how will it affect other activities in the economy? On a higher level, the course also looks into the current structure of society, being economical in its nature, and the core concepts that structure it. On the entrepreneurial side, several forms of enterprises are considered (limited, incorporated, cooperative…)
- **Social**: Is there a social impact when the new technology is introduced? Will people need to change their behavior? Does it make the technology available to more people or does it leave out certain groups? On a philosophical level, the course discusses approaches to well-being, money-based or otherwise.
- **Ethical**: philosophically speaking, what can we say about the new approach? What have philosophers said about similar changes in society? How can we look at the morality issue towards past and future generations ?

After discussing a number of topics using these four approaches, students make a documentary about a topic of their choice. In a ten minute video, they highlight both the arguments pro and against the subject. In the first five minutes of the video, the students document all the positive sides, using arguments of each of the four angles. This part should be clear and leave no room for doubt. The students then highlight the negative side of the story in a second part. This age-old technique of practicing argumentation for as well as against is a good exercise in looking at a subject at all angles and it prepares them for critique during the development of real-life projects.

Two year master path

Group T considers the project of the master program to be the ideal place to let students experience what it means to be an engineer. The path expands the standard master program with an extensively elaborated real-world project. All aspects of these master projects are handled by the students, with the teaching staff acting as coaches and experts. The idea for each of the three example projects described below came from the students. They manage finances, relationships with the industry, all organization and operations, marketing, R&D and all other aspects of the project.[16]The commitment and the involvement of the students is of a degree rarely seen in student projects. For example, when in 2012 the building housing the projects was destroyed in a fire, the students took to their phones and succeeded in finding new housing to continue their work. The result is ambitious teams that continue working even after their initiators have graduated. Some examples.

- **Solar Team**: Started by a group of students, the team develops cars that compete successfully in the World Solar Challenge races in Australia. Aside from the technical aspects of the car and the races, the team is also responsible for the relations with the industry, the PR, arranging transport, and the financial aspects of running the team
- **Formula Group T**: This team builds electrical race cars that compete in the Formula Student competitions against other European teams. Despite having started only in 2011, the car made a positive impression in its first race in 2012. The team built on experience of another Group T team that worked on an electrical version of the Citroën 2CV. This effort has attracted attention from the media and a price for the entrepreneurial skills of the students involved.
- **Core cvba**: To continue efforts on sustainability even after graduation, a group of students and docents of Group T have set up a cooperative to promote rational energy use. Student housing frequently has shared energy metering, which makes it hard to measure the impact of a student's individual behavior. Core aims to raise awareness amongst students by engaging in highly visible projects and by working on student housing itself. In one project, Core has done the first detailed study in Belgium to reuse the heat of a waste incineration plant for heating of residential buildings. The plant generates 18 MW of heat that will be used to heat water to be used for heating in the nearby living areas, reducing the local usage of fossil fuels for heating. Core has also received funding from the European Social Fund to work out a blueprint sustainable student housing. The blueprint includes a study of low energy usage, including the sourcing of local vegetables, and will be a cooperation of the housing owners, the students as well as the building companies.

5. CONCLUSION

Many contemporary reforms of engineering education realize that the world is changing. By adding projects and a broader skillset, they enhance the profile of the engineer. Such an approach is praiseworthy but falls short of truly emancipating the engineer. By looking at the position of the engineer in the world, we find that a change in world view is required to establish the engineer as a responsible mediator between technology, culture, and the world. This type of reform is ambitious and harder to achieve than learning new tools or changing an attitude. It is also a balancing act. Even with a new mentality and world view, an engineer still requires strong technical and soft skills.

[16] This is a key difference with the approach of the Franklin W. Olin College of Engineering. While their general approach to education is similar to Group T's, the scope of intra-curricular projects is tightly limited. Students can of course not be stopped from pursuing other aspects of a project outside the curricular activities, which does happen in student clubs. Olin College does involve the students in other parts of the education that help build on the world view Group T is also pursuing. For example, students are frequently involved in setting up the content and structure of new courses.

The approach proposed in this paper therefore has its own challenges. For example, the method of evaluation must different than the one for traditional courses. A case study with an electronic engineering portfolio demonstrates this: one cannot compare a student's answers to the "correct" answers or even with the work of other students [13]. At the same time, the student still needs to get a final evaluation. This is done by combining a test of the final skills with the progress that the student has made over the evaluation period, and this for technological skills as well as soft skills.

Despite these challenges, we think the ambition of building a more self-conscious, open, and creative engineer is a lofty one to strive for. It offers a movement counter to the current trend of fixing things into the known and dives back into the unknown from which creativity is possible. This trend of sticking to the known has now even appeared in creative art education where it is considered stifling and asphyxiating: "Increasing bureaucracy, the will to measurability, and neoliberal rationalization hollow out the 'school' in its original sense: as a space of 'free time', decoupled from the politico-economic order, that enables a young generation to take an interest, in an unknown way, in what we already knew. This emancipation of the unknown is what the 'measuring-is-knowing' discourse threatens." [29].

Stepping back into the unknown allows us a wider perspective on what we are trying to do. Instead of focusing on the technological means as a goal in itself, it allows us to wonder about our intended goal. In some cases, we may decide a radically different technology works better or that technology is not even needed. For example, changing the dress code of businessmen decreased the power consumption of air conditioners in Japan [18]. We can ask ourselves whether we can achieve what we want with other and simpler means, or whether we are working on the right project at all. A supreme example of this open mentality can be found in Thoreau's Walden:

> *"One says to me, "I wonder that you do not lay up money; you love to travel; you might take the cars and go to Fitchburg today and see the country." But I am wiser than that. I have learned that the swiftest traveller is he that goes afoot. I say to my friend, suppose we try who will get there first. The distance is thirty miles; the fare ninety cents. That is almost a day's wages. I remember when wages were sixty cents a day for laborers on this very road. Well, I start now on foot, and get there before night; I have travelled at that rate by the week together. You will in the meanwhile have earned your fare, and arrive there some time tomorrow, or possibly this evening, if you are lucky enough to get a job in season. Instead of going to Fitchburg, you will be working here the greater part of the day." [27]*

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BIBLIOGRAPHY

[1] Afshar, S.S., Flores, E., McDonald, K. F. and Knoesel, E. (2007), Paradox in Wave-Particle Duality, *Foundations of Physics*, Vol. 37, No. 2, pp. 295-305.

[2] Austin, J. H. (1999), Zen and the Brain, MIT Press, Cambridge.

[3] Beedle, M., van Bennekum, A., Cockburn, A., Cunningham, W., Fowler, M., Highsmith, J., Hunt, A., Jeffries, R., Kern, J., Marick, B., Martin, R. C., Schwaber, K., Sutherland, J., Thomas, D., Manifesto for Agile Software Development (2001), Agile Manifesto, http://agilemanifesto.org.

[4] Committee on Science, Engineering, and Public Policy, Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future (2001), The National Academies Press, Washington.

[5] Crawley, E., Malmqvist, J., Östlund, S. and Brodeur, D. (2007), Rethinking Engineering Education, The CDIO Approach. Springer.

[6] De Graeve, J. (2002), Paradox-Based Strategy for Innovative Engineering Education,Beijing Normal University, Beijing.

[7] Doob, L. W. (1947), The behavior of attitudes, *Psychological Review,* Vol. 54, No. 3, pp. 135-156.

[8] Gillett, J. E. (2001), Chemical Engineering Education in the Next Century, *Chem. Eng. Technol.*, Vol. 24, No. 6, pp.561-570

[9] Grasso, D. and Martinelli, D. (2007), Holistic Engineering, *The Chronicle of Higher Education,* Vol. 53, No. 28, pp. B8.

[10] Hansen, R. (1997), The Value of a Utilitarian Curriculum: The Case of Technological Education, *International Journal of Technology and Design Education*, Vol. 7, pp. 111-119.

[11] Hansen, R. and Froelich, M. (1994), Defining Technology and Technological Education: A Crisis, or Cause for Celebration?, *International Journal of Technology and Design Education*, Vol. 5, No. 1, pp. 179-207.

[12] Hofstadter, Douglas R. (1979), Gödel, Escher, Bach: An Eternal Golden Braid, Vintage Books, Blacksburg.

[13] Ilsbroux, I. and Lodewyckx, K. (2012), An Electronic Portfolio Instrument in Industrial Engineering Education, GROUP T International University College, Leuven.

[14] Jamieson, L. H. and Lohmann, J. R. (2009), Creating a Culture for Scholarly and Systematic Innovation in Engineering Education: Ensuring U.S. engineering has the right people with the right talent for a global society, American Society for Engineering Education, Washington.

[15] Kinsella, E. A. and Pitman, A. (2012), Engaging Phronesis in Professional Practice and Education, *Professional Practice and Education*, Vol. 1, pp. 1-11.

[16] Lang, J. D., Cruse, S., McVey, F. D. and McMasters, J. (1999). Industry Expectations of New Engineers: A Survey to Assist Curriculum Designers, *Journal of Engineering Education*, Vol. 88, No. 1, pp. 43-51.

[17] Leverhulme Study Group (1961), The Complete Scientist – An Enquiry into the Problem of Achieving Breadth in the Education at School and University of Scientists, Engineers and Other Technologists, Oxford University Press, London.

[18] Maex, E. (2009), Open Mind,Witsand, Gent.

[19] Melville, W., Campbell, T., Fazio, X. and Bartley, A. (2012), The Departmental Script as an Ongoing Conversation into the Phronesis of Teaching Science as Inquiry, *Journal of Science Education And Technology*, Vol. 21, No. 6, pp. 835-850.

[20] Members of the 2005 "Rising Above the Gathering Storm" Committee (2010), Rising Above the Gathering Storm, Revisited: Rapidly Approaching Category 5, National Academies Press, Washington.

[21] National Academy of Engineering (2004), The Engineer of 2020: Visions of Engineering in the New Century, National Academy of Sciences, Washington, pp. 55-56.

[22] Olson, J. C. and Mitchell, A. A. (1975), The Process of Attitude Acquisition: the Value of A Developmental, Approach to Consumer Attitude Research, *Advances in Consumer Research*, Vol.2, pp. 249-264.

[23] Shimpi, A. L. (2012), Intel: By 2020 The Size of Meaningful Compute Approaches Zero, Anandtech, http://www.anandtech.com/show/6253/intel-by-2020-the-size-of-meaningful-compute-approaches-zero.

[24] Shuster, M. D. (2008), The Arts and Engineering, *IEEE Control Systems Magazine*, Vol. 28, No. 4, pp. 96-98.

[25] Smith, K. K. and Berg, D. N., Paradoxes of Group Life: Understanding Conflict, Paralysis, and Movement in Group Dynamics,Jossey-Bass, San Francisco.

[26] Takala, A. and Korhonen-Yrjänheikki, K. (2011), A National Collaboration Process: Finnish Engineering Education for the Benefit of People and Environment. *Science and Engineering Ethics*.

[27] Thoreau, H. D. (1854), Walden. http://thoreau.eserver.org/walden00.html. (online edition).

[28] University of Waterloo (2012). Why co-op? https://uwaterloo.ca/co-operative-education/why-co-op/benefits (accessed October 01, 2012).

[29] Van Imschoot, T. (2012), Kunst In Wording, *Rekto Verso*, May-June 2012, pp. 4-5.

[30] WACE (2011-2012), Best of Coop Guide, University of Massachusets Lowell, Lowell.

[31] Wilber, K. (2001), A Brief History of Everything, Shambhala, Boston.