TOTAL ENGINEERING EDUCATION II

Editor
Shan-Dong Tu

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Contents

Preface

Facing the global economic depression, we need courage and wisdom. We have to plan for the future, but rethink the past. There is no exception for engineering education. New paradigms should be developed to avoid the future failure. The concept of Total Engineering Education (TEE) provides a philosophical framework to develop the new engineering education for the future. Having the belief of "engineering for all and engineering education for all," TEE advocates that engineering education be implemented in *all stages* of education, beginning from our children in pre-school and kindergarten programs, through high school graduation, to graduate education and continuing education. TEE should be *all inclusive* in content to enable the students to see both the trees and the forest of an engineering issue and is committed to the total education of the individual as a social being. Furthermore, TEE should help *all people* to understand the engineering basis and appreciate the impact of engineering on socio-cultural systems and recognize engineering's ability to address the world's complex and changing challenges.

Following the success of MIDEE symposium (International Symposium of Multi- and Inter-Disciplinary Engineering Education) in August 2006, many engineering educators and engineers hope to continue our discussion on Total Engineering Education. In October 23-25, 2009, the second symposium of total engineering education was held at Shanghai. More than 80 participants from Canada, Czech, Korea, Germany, Japan, India, Slovak, Sweden, USA, UK and China attended the event. The technical program included 4 plenary lecture sessions with 6 parallel sessions, and 3 panel discussions. Emphasized were the dialogue on cooperative education between engineering educators and practicing engineers. Potential models of engineering education were discussed. Among the topics covered are internationalization, distant engineering education and others that might be incorporated into the engineering curricula. We are delighted to see that great progresses in engineering education reform have been made in many educational institutions after the symposia.

This book contains the selected papers presented in the last symposium and from the recent research works of Department of Engineering Education, East China University of Science and Technology. In the publication of the book, I would wish to thank the supports from the science and engineering department of Ministry of Education and our partner universities including University of Saskatchewan (Canada), Lehigh University (USA), Utah State University (USA), and Malardalen University (Sweden) for co-sponsoring the event. In particular, I am indebted to Bayer Technology Service (Shanghai) who has been enthusiastically involved in the process of promoting the concept of total engineering education by setting up Bayer Teaching Excellence Award. I would also wish to thank the authors who contributed to this book. Special thanks are due to Professor Zhou Ling and Professor Zhou Shaoping who spent a lot of efforts in communication with the authors and editorial details.

Shan-Tung Tu

East China University of Science & Technology
December 24, 2011

The future of engineering education: Towards totality and harmony

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Abstract

The first decade of the 21st century is facing relentless challenge from financial crisis, technology failure and ecological change at the global scale. A reform of current engineering educational system may alter the course ahead for the better. Such an expectation requires the coagulation of wisdom and cooperation of engineering educators, administrators and engineers. In 2006, the author proposed the concept of total engineering education in order to alleviate the deficiency of current engineering education system. The core value of total engineering education will be further reviewed in light of the current industry needs for developing cooperative education with the mechanisms of distant engineering education, multi- and inter-disciplinary engineering, not to mention the emphasis on engineering ethics. The lectures presented at the 2009 international symposiums on total engineering education and progresses in recent years can serve as the basis of engineering education reform courses. It is anticipated that the general trend of engineering education moves towards a more harmonic paradigm, involving the technical as well as the social issues.

Keywords: Total engineering education; Harmony; Strategy.

1. Introduction

The concept of Total Engineering Education was first proposed in an international symposium of "Multi-disciplinary and Interdisciplinary Engineering Education (MIDEE)", August 16-20, 2006. A forum was provided to review the present engineering education systems such that they can be further enhanced to meet the future needs. This is a multifaceted challenge that entails government policy, social demand and most of all being relevant to a sustainable global economy. The totality of the well being of a society starts with education, to which engineering plays a major role in today's emphasis on the world economy. Many of the associated factors should be weighed with an engineering approach. The incorporation of an inter- and multidisciplinary curriculum can be best achieved under the umbrella of a team of international experts in the field.

The second symposium of total engineering education was thus held at Shanghai in October 23-25, 2009. More than 80 participants from Canada, Czech, Korea, Germany, Japan, India, Slovak, Sweden, USA, UK and China. The technical program included 4 plenary lecture sessions with 6 parallel sessions, and 3 panel discussions. Emphasized were the dialogue on cooperative education between engineering educators and practicing engineers. Potential models of engineering education were discussed. Among the topics covered are internationalization, distant engineering education and others that might be incorporated into the engineering curricula.

This paper reviews the progresses of total engineering education in recent years. It is anticipated that the general trend of engineering education moves towards totality and harmy.

2. The basics and new development of total engineering education

Engineering education should address technological advancements such as bioengineering and biotechnology, information and communication technology and miniaturization (MEMS, nanotechnology, and advanced materials), not to mention their operational sustainability to avoid premature malfunction.

The growing complexity and uncertainty asso-

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ciated with the interdisciplinary and multidisciplinary can no longer be ignored in the present-day engineering systems. The changing ecological environment adds another dimension to the involvement. The disparity between the "Haves and the Have Nots" is now a global issue that is electronically transparent to the world at large. These considerations have called to the need of Total Engineering Education (TEE), which entails *specialization* within the engineering discipline and yet demanding *generalization* for all aspects of the societal influence. TEE advocates that engineering education be implemented in *all stages* of education, beginning from our children in pre-school and kindergarten programs, through high school graduation, to graduate education and continuing education. TEE should be *all inclusive* in content to enable the students to see both the trees and the forest of an engineering issue and is committed to the total education of the individual as a social being. Furthermore, with the belief "engineering for all and engineering education for all", TEE should help *all people* in and out of school to understand the engineering basis and appreciate the impact of engineering on socio-cultural systems and recognize engineering's ability to address the world's complex and changing challenges [1,2]. The intention of TEE, however, is not problem solving but rather to emphasize the totality aspects of engineering education that is viewed as the weighting factors, rather than the answers. Changes and uncertainties must be allowed for the future generation to consider. This is also an important feature of TEE.

In the plenary lecture " Total engineering education in the 21st century" [3], Sjursen (Professor of Philosophy of Technology and Global Ethics, New York University Polytechnic Institute) stressed that the precepts of Total Engineering Education provide a philosophical framework to consider the challenges of the 21st century. Possible strategies for the achievement of the objectives of TEE should include the application of CDIO (Conceive- Design- Implement- Operate) [4,5], TRIZ(Theory of Inventive Problem Solving) [6], and a "blue ocean strategy" [7]. The new engineering imperative to innovate, born from both the desire for the new and a responsible vision of the past, of lust and caution, requires a radical embrace of and dialogue with those forms of culture that are most resistant to innovation, that in the spirit of *Lao Zi*. Sjursen suggested that the principles of TEE, however they are manifested – and certainly cultural variations are desirable – must be played out on the global stage in full view of the world community, in a kind of theater in the round where collaboration and mutual support have leading roles. Tu and his colleagues proposed a CSSO model for entrepreneurship education in order to provide students a full training covering the whole life cycle of a business, i.e. Conceive- Scheme- Simulate- Operate [8,9], which is also an indispensible part of TEE. Similar to CDIO, CSSO aims to educate students who understand how to Conceive- Scheme-Simulate- Operate complex profit added business in a modern team-based business environment, and are innovative, mature and thoughtful individuals.

Halstead (Pro Vice Chancellor, Aston University) briefed the challenges for engineering education in the UK and the implementation of total engineering education in the university [10]. It was shown that the percentage of engineers in UK undergraduate population is low and failing, and the percentage of students intending to work in engineering on graduation in declining. The UK industry's feedback indicated that there is a worsening shortage of high calibre UK engineering graduates. The shortages are impacting productivity, creativity and growth of economics.

To improve the situation by stimulating the students' interest in engineering, Halstead highlighted the Aston University's strategy for total engineering education. The university is working with local Schools to raise aspirations of children from 4-13. Aston Engineering Academy was planned to be built next to the University for 2012. In the TEE framework, pedagogical research with 'Purpose for Practice' would be strengthened.

"Cooperative education with industry" has been an important topic. The intent is to integrate classroom theory with practical work experiences in the student's area of study. The industry will also have the opportunity to influence the learning process by working with professors and students. A number of engineers were hence involved in the symposium.

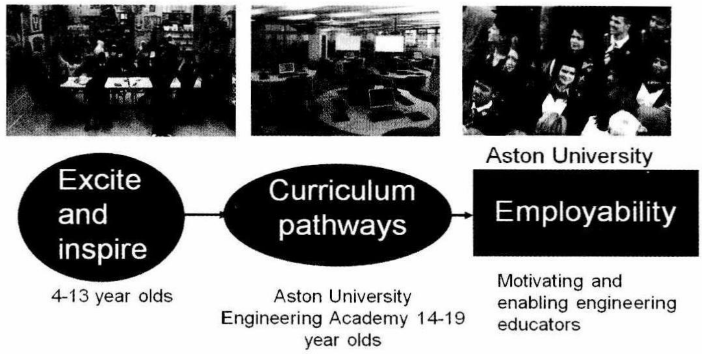

Fig. 1. ASTON's Strategy of Total Engineering Education.

Heinz (Head of the Process Technology Division, Bayer technology service company) gave a lecture on "The innovative and enlightenment of engineering education" [11]. He suggested that future engineers should have the following characteristics: Interdisciplinary, Be a team player, Intercultural, Understand business and ethical consequences of a technology. In the discussion, Delegate from Emerson emphasized that an engineer should be Customer driven and recognize that customers determine the definition of value, Commit to continuous improvement and seek opportunities where ever possible to pursue excellence, Creative, open-minded and willing to embrace new ideas and challenge the status quo, Good team spirit and high business integrity; High Learning Agility. Most of the panelists agreed that life long learning, integration of engineering ability and social responsibility are indispensible and should be the fundamentals of our engineering educatiion. Fig. 2 shows the penelists in industry needs.

Facing the complexity of mega engineering, how should engineering education respond to the challenges? Wang (Director of Engineering, Suncor Energy) emphasized the importance of including engineering management in engineering education [12]. This is due to the increasing difficulty to manage the designs of mega engineering projects. The globalization and modern tools have added more challenges. And severe shortage of engineering management expertise becomes a worldwide problem. As shown in Fig. 3 is what inside the Airbus 380. The fuselage has a length of 73 meters with 100,000 electric links and 530 km wires. The wing only consists of 32,000 elements. Such a large and complicated engineering system may need the joint efforts of more than 1000 designers and services from more than 1000 suppliers. Many examples of mega projects in power generating, petrochemical, transportation industries demonstrate the importance of engineering management. Engineering management is believed to be the core to the success of a complex project and critical to a nation's development and industrialization. We hence need to train top engineers to undertake this business, which is also a great opportunity for engineering schools. To promote engineering management, we should encourage the collaboration among government agencies, industry associations, engineering companies, research and teaching institutions, and business owners in various industries.

Fig. 2. Panel discussion: Needs from Industry.

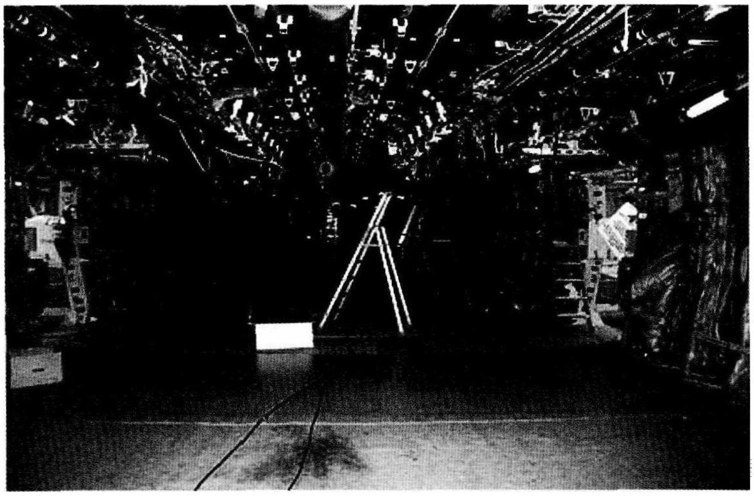

Fig. 3. An example of mega engineering - Airbus380.

The UNESCO chair professor of university-industry cooperation, Zha proposed the strategy for university and industry cooperation which includes the development of rationales for university-industry cooperation and learning experiences from best cases in practice [13].

Engineering ethics and culture is also a great concern of today. It is good to see that many engineering companies hold a high standard of ethics. What reflected in value statement of participant companies are "To conduct all business according to the highest professional and ethical standards and practices" (Siemens), "better science better life" (Bayer), and "a passion for progress and integrity" and " insisting on the highest ethical hehavior" (Emerson). These values are essential to ensure the compatibility of modern engineering and technology with our human and nature.

When many educators and engineers urge the return to engineering and system integration, we are probably in a dilemma of science-based education and specific engineering knowledge transfer. Sih (Emeritus Professor, Lehigh University) believed that the future engineers should be able to design, manufacture and operate micro- and nano machines [14]. This may mean that the fundamental knowledge provided in current bachelor and even master level will not be sufficient. More fundamental knowledge at micro- and nano- scales should be required, which gives additional challenges to higher Engineering education.

With the rapid development of computer and network technology, "distance education" is being accepted as an important way to promote the engineering education for publics. How to improve the efficiency of learning and strengthen the practice experience in a remote way is also an important topic. The learning pyramid shown in Fig. 4 proposed by American National Training Laboratory indicates that cooperative learning and practice are the most effective ways to improve our learning, which enlightens the future direction of distance engineering education [15].

Huang, from one of the biggest distance education companies in China delivered a lecture on development of Next Generation E–Learning. Distance education has been practiced in China for more than 10 years. The students had been receiving distant lecturing in a more or less passive way for the purpose of obtaining degrees, certificates and skills. It was anticipated that in the next 10 years students will be actively engaged in distance learning by cooperative learning, sharing and discussion in the virtual learning community [16], which will follow better the learning pyramid rules.

Endean from Open University UK presented a lecture on Educating engineers through distance learning [17]. He believed that the global demand for qualified people must rely on the increasingly growing distance education. There is a responsibility on the whole community of engineering educators to contribute to innovation in engineering education that will make the experience of distance learners even more rewarding. He also advocated integrating the activities between the online world and the real world. Wu from North Carolina State University described a real-time interaction education case [18], in which a concurrent and expanding effort on interactive remote education between Duke University in the USA and East China University of Science and Technology in China was taken. This promoted the internationalization of teaching and learning and allowed students to share high-quality education resources. The laboratory skills have been a major obstacle to implement the distance engineering education. Recent progress in distant experimentation and e-laboratory achieved by East China University of Science and technology, Tomas Bata University in Zli and University of Trnava gave people much more confidence in further development of distance engineering education.

Engineering education models is one hot topic in the panel discussion. It is believed that it is not necessary to be a standard or model though ABET, IChemE and many other organizations have proposed criteria in engineering education. CDIO is a good practice but may not be the only calibre for all. It is unrealistic to develop an engineering education standard or model for people to follow due to the diversity of nations and universities. Another hot discussion topic is the popularization of engineering education through distance education which could significantly reduce the engineering education cost. It is well agreed that distance engineering education should be developed to allow the education from elite to grassroots. These questions are very open and leave much room for the people to think about. Figs. 5 and 6 are panel discussions about engineering education model and distance engineering education.

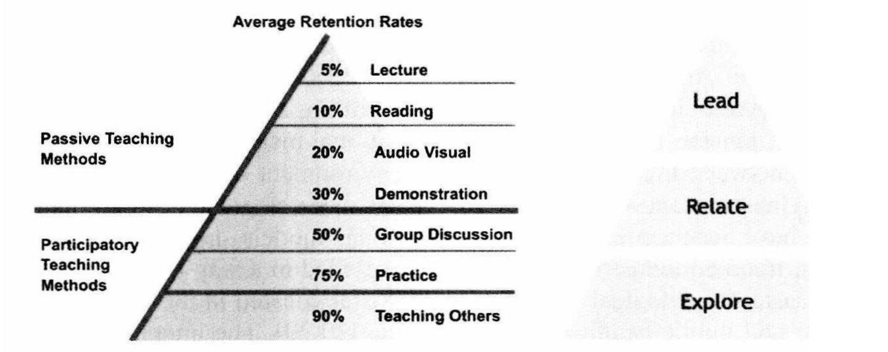

Fig. 4. Learning pyramid proposed by National Training Laboratory.

Fig. 5. Panel discussion: Are there any standards and models?

Fig. 6. Panel discussion: Engineering Education from elites to grassroots?

3. Towards harmony for the future

The rapid change of global state of affairs has exerted enormous pressure on the educational institutions to look for answers to better prepare the younger generation to cope with the future challenges. This may be partly attributed to unawareness of the decision makers to anticipate the changes arising from the industrial revolutions that should have been known from the past to extrapolate for the future. As we know that the rapid changes of the world have caused many tensions, including the tension between different social strata, tension between human and nature, tension between engineering and world, and so on. These tensions have resulted in many risks such as social unrest, frequent industrial accidents, frequent natural disasters, ecological and environmental problems, and public health incidents. Such series reactions are not uncommon in history. But who is responsible for a repeat in the 21st century? While TEE has volunteered to share the burden, the bottom line rests on the public at large.

We believe that TEE should not only stay at *totality* but also make engineering education a symphony. It should be so grand that it can provide beautiful harmonies between people and educational means, between nature and technologies that are being taught, between all people within our educational systems.

It is first of all human centered that strive to achieve inner harmony of the educatees. The process that converts knowledge into personal quality should be pleasant. As it is well recognized that interests are the best teacher, the future engineering education should thus retain the great interest of educatees in engineering. We have to allow the children in their early days of playing games to experience the joy of using technology to change the world and make benefit for people. The students in university and high schools are able to appreciate the beauty of engineering which covers the mega engineering of today and micro- and nano- engineering of tomorrow, and are willing to make contributions to advancement of engineering science and technology so as to make a better world.

Secondly, it shall provide an excellent compatibility and harmony between people and educational means. With the change of socio- culture environment and technology advancement, there has been a great need of innovation of educational models. Engineering education should be provided in a way that is enjoyable to students as it is advocated in the so-called game based learning [19,20]. The important features of the current learning methods, such as project based learning, learning by doing, CDIO and CSSO have been aimed to stimulate the students' interest in learning and thus achieving a harmony with the students. Technically, it may be possible for students to improve their engineering abilities and skills through an "online game" in the network based learning community. Our students will find a great fun from "upgrade" in the virtual engineering world.

Thirdly, it shall facilitate the harmonization between technology and nature and society. In the world of engineering, the harmony between human and nature depends greatly on the compatibility of nature and engineering technology that are developed by human being. An engineering project may endanger nature in long run if it is not energy saving and / or environment friendly. Thus the future engineering education should emphasize more the engineering ethics. The future engineers will observe the ethics and take the social responsibility so as to achieve a great harmony between technology and nature.

In conclusion, none of the above can be accomplished without the devotion of those who are willing to sacrifice in fame and financial gain but to choose a prudent life of teaching students. The inner harmony of engineering educators is thus of primary importance. The future engineering educators will have this very unique happiness of self fulfillment. They will feel more joy in the education innovation and the process in cultivating excellent engineers. They are professors by profession and of passion and of compassion.

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Author's Biography

Shan-Dong Tu, an advocator of total engineering education, is a vice president of East China University of Science and Technology and a professor in the School of Mechanical Engineering. He received B.Sc degree in 1982 and Ph.D degree in 1988 from Nanjing University of Technology.

His research covers time-dependent fracture mechanics, structural integrity, mechanical reliability, development of energy materials and novel heat transfer equipment. He is an author of more than 300 papers and received a number of distinguished awards, including China National Science and Technology Progress Award, National Teaching Achievement Award, China Youth Science and Technology Award, ASME Best Paper Award and so on. He is currently a consulting member of China State Council for engineering thermophysics and power engineering, the honorary President of Chinese Pressure Vessel Institution and The president of Chinese Materials Institution, CMES (2010-), and members of editorial boards of *Int J Pres Ves and Piping*, *J Applied Energy*, J of Materials Science & Technology, Frontier of Mechanical Engineering, *Advances in Mechanical Engineering* and so on.

Total engineering education in the 21st century: CDIO, TRIZ, global collaboration and blue ocean strategies

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Abstract

The reflections that follow the fundamental precepts of *Total Engineering Education* will be examined in the light of some contemporary circumstances related to the globalization of technology, the imperative to innovate, and the benefits of collaboration. Possible strategies for the achievement of the objectives of TEE will be suggested including the application of CDIO, TRIZ and blue ocean strategy. The issue of engineering responsibility will be kept at the center of these reflections. The discussion will be in the double context of contemporary trends in technology and east Asian traditions.

Keywords: Total Engineering Education; CDIO; TRIZ; Blue ocean strategy.

The large question before us is simply, "How can engineering education meet effectively the conflicting set of needs and challenges of the 21st century?" Although the large question may be easy to state it is far from simple to imagine a straightforward operational plan for an engineering curriculum that will address these challenges. The precepts of Total Engineering Education provide a philosophical framework to consider these challenges. In the reflections that follow the fundamental precepts of Total Engineering Education will be examined in the light of some contemporary circumstances related to the globalization of technology, the imperative to innovate, and the benefits of collaboration. Possible strategies for the achievement of the objectives of TTE will be suggested including the application of CDIO and TRIZ. The issue of engineering responsibility will be kept at the center of these reflections. The discussion will be in the double context of contemporary trends in technology *and* east Asian traditions. Questions will be guided by the example of a recently developed integrative engineering curriculum.

Part I

Several presuppositions guide the reflections in this presentation:

- Modern technology depends on multiple layers and types of collaboration.
- Often such collaborations are international and multicultural, involving especially India and China.
- China and India are becoming technological centers of gravity in the world of the 21st century, but their practices depart in *cultural* ways from those familiar to the West.
- Various regions within Asia, often dominated by either China or India, have urgent economic incentive to develop collaborative technology clusters within their own sphere of influence.
- Many of the technology and engineering leaders in China and India received their professional training in the United States or Europe, creating a basis of understanding necessary for successful collaboration.
- This creates an opportunity for engineering and technology entrepreneurial firms in the West to participate in the economic rise of China and India *and* a new set of challenges for technological universities in the West. Engineers need to understand how their particular contribution, while different than pure innovation, is both essential and beneficial to creative techno-science.

It is increasingly the case that technological innovation depends upon effective collaboration. Among the obvious reasons for this are that very few technologies *stand alone*; technologies themselves are natural collaborators. Google, the

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world's largest and most successful internet search engine, in the vast majority of instances, runs on the Internet Explorer browser designed and distributed by its corporate arch rival Microsoft. The relationship between Google and Microsoft is truly symbiotic, the success of each dependent to a great extent upon that of the other. The browser came first but its utility and value were overwhelmingly enhanced by the supplementation of an efficient search engine. Thus in this symbiotic relationship Microsoft and Google are each responsible for the health and well-being of the other.

This type of relationship points to the character of successful technology collaboration.

The observation extends and renders problematic the meaning of both collaboration and responsibility. The idea of collaboration is unusual because, while not *sub rosa* is not acknowledged by a MoU or other instrument of cooperation. Indeed a kind of paradox is elicited as these two corporations are supposed to be in competition and, as recent legal history reminds us, Microsoft has been judged as being too dominant in the marketplace. In order to sustain their near dominant position it is necessary that Microsoft – advertising for *Bing* (including the recently announced merger with Yahoo) to the contrary – not take over the search engine market. If they did they would risk the prospect of being broken up under various anti-trust provisions. Of course this is not absolutely clear because of the global character of the Internet. The regulatory environment differs from the United States to Europe to Asia. And so collaboration is presented as competition and as an engine for innovation.

With the notion of responsibility the situation becomes if anything even more murky. As both Microsoft and Google are public firms a *prima facie* responsibility is the fiduciary duty each has to its shareholders. Does such responsibility have any connection to a possible responsibility to innovate and improve existing technologies? If the successful implementation and reliable operation of Internet communications are in the public interest, and if corporations like Microsoft and Google are the means to sustain this capability, then there would surely seem to be a kind of responsibility to improve existing technologies. But what is the nature of this responsibility and where should the agency be located? This question becomes more complex when one recognizes the disorderly character of technological innovation and the inequities of the global workplace.

Let us concede first that whatever the nature of the responsibility to improve technology is, that it is a *human* responsibility. By this is meant that the agency must be distributed among humanity and not given over fully to proxies (such as corporations or governments). Correlatively the improvement of technology should be *for the sake of* humanity at large and not the means to corporate or national hegemony. This suggests that the responsibility to improve technology should be open, i.e., non secret, in the same way that scientific research is open. This of course raises a host of problems which shall be addressed subsequently. However the ideal of openness in technology development is consistent with collaboration.

Moreover technology innovation seems to work best in a highly collaborative and open environment as evidenced by the *open source* software movement. Open source software (or at a distance, perhaps, from pure or scientific technology, Wikepedia) emulates a skunk-works like environment conducted in an open virtual space. This space transcends legal jurisdictions, traditional cultures, political borders and (for the most part) natural boundaries. In fact this type of collaboration favors radical openness with efforts to keep it closed constantly challenged by technology itself. Yet a tension persists between the expectations embedded in a particular cultural tradition and the more or less free floating attitude of technology *per se*.

There are numerous incentives supporting technological collaboration (expressed in popular cliches):

Necessity is the mother of invention. Invention or innovation is a response to desire or need. The inventor is one who perceives an unfulfilled desire or practical necessity and takes action to satisfy it. A plurality of inventors therefore multiplies the number of recognized needs and desires which in turn multiplies the number of attempted solutions. Since only some solutions will work and of those some will work better than others a coordinated multiplicity, i.e., collaboration greatly increases the likelihood of an effective solution being discovered.

There is no need to reinvent the wheel. Tech-