2006-835: TRANSFORMING ENGINEERING EDUCATION FOR MEETING THE REQUIREMENTS OF THE GLOBAL INDUSTRY - PIONEERING THE USE OF THE SYSTEMS APPROACH IN EUROPE

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2006-835: TRANSFORMING ENGINEERING EDUCATION FOR MEETING THE REQUIREMENTS OF THE GLOBAL INDUSTRY - PIONEERING THE USE OF THE SYSTEMS APPROACH IN EUROPE Simo Lehto, Helsinki Polytechnic Simo Lehto's experience includes scientific research, high-tech R&D and product development, entrepreneurship, management and organizational development, and teaching and education development in higher professional and academic education. He received the degrees of MSc. in 1967 and Lic. of Tech. in 1970 from University of Oulu, Finland. He was Acting Professor of Electrical Engineering at University of Oulu in 1970-73 and 1975-78. At University of Oulu his research fields were industrial process dynamics, electronics, and wireless communications. During the 1970s and 1980s he did high-tech R&D and product development as an entrepreneur. During 1998-2000 he worked as Project Manager for a Digital Radio project. He started the EE development work in the 1970s. During 1978-83 he was manager of the Further Education Organization at University of Oulu. He continued EE development at Kymenlaakso Polytechnic in the 1990s. Since 2001 he has been Project Manager at Helsinki Polytechnic for the R&D work aimed at restructuring EE for meeting the needs of the global industry in Finland.

Transforming Engineering Education for Meeting the Requirements of the Global Industry - Pioneering the Use of the Systems Approach in Europe

Abstract

The paper describes the ongoing work carried out in Finland since the early 1990s aimed at restructuring engineering education (EE) for meeting the requirements of the European high-tech industry in the 2010s. The increasing global competition has forced the companies to make a transition from the repetitive (routine) mode of operation to the development (creative) mode of operation.

This qualitative change creates new requirements for EE, which can only be met by reengineering EE institutions accordingly. The complexity of this task necessitates a systematic theoretical approach. The systems approach used in Finland does not divide the world into disciplines. In handles the extreme complexity of the world by regarding it as collection of functional entities (systems) and describing them with appropriate models.

Modern engineering is very successful in the field of physical systems. The reason is that the nonliving systems can be described by accurate and general science-based models, e.g. by the Newton and Maxwell models.

In the EE development work in Finland, engineering education is considered as a complex multilevel system consisting of human beings. People (e.g. the students) are also described as complex living systems, which have been designed by evolution over millions of years. The basic structure and function of the human being, including learning as an important component, has been modeled by using the latest results of the relevant sciences (e.g. evolutionary psychology, cognitive science, neuroscience, biology, genetics, and educational science). The work has shown that the human being can be modeled as a dynamic, parallel, and hierarchical system, which is internally driven by a genetically programmed control system.

The use of the systems approach has led to a new EE structure. A sequence of learning projects connected to the real world is used as the vehicle for supporting and guiding the individual learning processes of the students and realizing an efficient learning environment for the whole study period. Group work, teamwork, and project work are used as an integral part of the new structure. The reengineered EE corresponds closely to the mode of operation and organization of international companies. Therefore, it removes the structural and functional discrepancy between the EE institutions and their main customers: the global high-tech industry.

The new approach, which utilizes a unified engineering-type model for the human being, has created a possibility for carrying out the EE development work as a systematic engineering work in cooperation between engineers and human scientists. The use of the systems approach for the development of new EE is an example of extending the efficient working methods of engineering from the physical world to the realm of complex social system as cooperation of engineers and specialists. The experience suggests that systems and model thinking opens interesting possibilities for bridging the gulf between engineering and the humanistic sciences.

Ongoing R&D work at Helsinki Polytechnic University in Finland

The paper describes the ongoing R&D work in Finland, which is aimed at developing and implementing a new mode and structure for engineering education (EE) for meeting the requirements of the companies operating within the international economy. The work is driven by the fundamental changes produced by the economic and cultural effects of globalization.

At the beginning of the 21st century, most of the world is moving rapidly towards a global, market-oriented, real-time economy. This transition has led to a dramatically rising level of know-how and use of technology. Driven by continuing market liberalization, the transition continues at an accelerating rate.

The increasing global competition between companies forces the routine operations (e.g. manufacturing) to be transferred to countries with low manpower costs. It also forces companies to adopt modern ICT (Information and Communications Technology) tools for automating routine work. At the same time, the global development is progressing towards the fulfillment of the basic human needs and, consequently, to the increasing emphasis of higher individual needs.

The routine work that repeats the earlier work is very effective, e.g. mass production of electronic products. It can be made more effective, minimized and automated by transferring it to modern ICT systems. Routine work, however, is not sufficient in the rapidly changing global business environment. The company cannot be successful in the global competition by repeating what is has done before or what others are doing elsewhere: systematic development work is needed.

The new requirements created by the increasing global competition and changes of societies can no longer be met by sporadic development. The situation forces organizations and people in the industrialized countries to make a fundamental transition: they must move from the repetitive (routine) operating mode to the systematic development (creative) mode. This shift demands a qualitative change in work methods, attitudes, organization, and management. In the global companies, the transition is being completed during this decade[20]. In most public organizations and educational establishments this transition is just beginning.

The renewal of higher education requires demanding long-term work. The students starting their studies in the fall of 2006 will enter working life during the 2010s and still be professionally active in the 2050s. The goal of the work of Stadia is the EE during the 2010s.

New approach at Stadia

The goal of the work in Finland is to develop and implement a new EE solution that meets the requirements of the companies operating in the complex global environment. The complexity of the development of the new structure requires a systematic theoretical approach. The work at Helsinki Polytechnic University (Stadia) is based on systems and model thinking, in which the world is described as a collection of dynamic, parallel and multilevel systems. The selected systems are modeled by using effective models of different forms. The description of the human being as a complex hierarchical system is central to this approach.

The new model is based on learning projects connected to the real world. The whole formed by these projects is used as the vehicle for creating an effective learning environment for the whole learning period. By using selected projects from the industry as part of the project sequence teaching and research can be combined and the new EE can be closely linked to the national innovation system.

Description of the work

The work in Finland has been carried out as an engineering endeavor as a concurrent combination of theoretical and experimental work, utilizing the new approach based on systems and model thinking. The work is based on the ideas and initial work done in EE at the University of Oulu in Finland during 1975-76. The basic structure of the student-driven real-world education has been developed in the continuing EE and entrepreneurial education of the University of Oulu during 1978-83[1]. The ideas published in the early 1970s have decisively contributed to this work[16,17].

The initial R&D work towards developing the new EE solution has been done as an engineering endeavor in 1993-97 at Kymenlaakso Polytechnic in southeastern Finland [2]. During 1998-99, the structure of the new model has been developed in an R&D project funded by the Finnish Ministry of Education and the European Union [3]. Parts of the new model have been pilot-tested during 1997-99 at the Department of Mechanical Engineering at Kymenlaakso Polytechnic.

Beginning in 2000, the development and implementation of new EE model has been continued at Helsinki Polytechnic University (Stadia). Since August 2001, the Faculty of Engineering at Stadia has developed and implemented the new model in the four-year BS Program of Industrial Management [4,5,6,7]. A one-year MS Program will be started in August of 2006. A team of some 25 faculty members and specialists have participated in this R&D work.

For supporting the work, the Centenary Foundation of the Technology Industries of Finland, which is owned by the Technology Industries of Finland, has granted US $ 0.5 million for the project ”Transforming Engineering Education for Meeting the Requirements of the Development Mode of the International Industry”. The financing is used for completing the work and starting the dissemination of the results to other EE institutions in Finland by the summer of 2007.

Responsibilities of universities in the change

The rapid change of the world places great requirements for the universities of Finland. They must assume a leading position when the nation is transferring itself to the uncertain and rapidly changing global era and, particularly in the training of the professionals needed in the future by the society and the industry.

Importance of engineering

The global competition also emphasizes the role of engineering and increases the requirements for engineers. The engineers play a central role in the social transformation, e.g. by being instrumental in transferring human routine work to man-made machines and systems. High-quality EE is very important to all nations, particularly small countries such as

Finland, which focus strongly on high-tech industries. These industries depend on the excellence of the engineers in the global competition. For the same reasons, high-quality EE is essential to the future of developing countries.

Discussion of the current EE in Finland

In Finland, a public debate about the EE ha been taking place during the past few years**.** The debate is very timely and important. The experts of EE have been waiting for it since the 1990s. The pioneers of higher education have already experienced the situation and started the first changes in the 1970s.

The parties participating in the debate are the industry leaders, industrial unions (Confederation of Finnish Industries Technology, Industries of Finland), professional unions (Union of Professional Engineers in Finland), the Finnish government (Ministry of Finance, Ministry of Education, Ministry of Trade and Industry), and the Finnish National Fund for Research and Development.

The debate includes words like ”top skills”, ”mediocrity”, ”global networks”, ”innovations”, ”capability of productizing the innovations for the global markets”, ”entrepreneurial spirit”, ”proactive”, and ”concrete decisions”. The reason why the representatives of industry use words like this is quite simple. In a competitive situation only one of the competitors is given the business. Because of this mechanism, the company has to be better than the competition for staying in the business. It must have better knowledge and better skills: this type of supremacy is only achieved by changing faster than the competition.

Problems of the current EE in Finland

The main problems of the EE in Finland are:

1. Heterogeneity of the students: large differences in basic knowledge and skills, management of personal life, and motivation.

2. Low starting level of knowledge for part of the students: conceptual thinking and systematic/logical thinking and functioning.

3. Lack for personal motivation for part of the students: second or third personal choice.

These problems lead to delaying of the studies and the increase the attrition rate. This is happening at the same time when new requirements caused by the globalization by the industry are placed on the students and the EE.

Although the level of education of the Finnish youth is the higher than ever before, part of the EE students does not have the readiness for university studies. These problems are international and common to all developed countries. The reasons are the great changes and structural reasons on the different hierarchical levels of the world from the global level to the level of the individual student.

The EE organizations must know the solutions to these problems. The solutions are collected from the industry and by following the changes on the relevant levels of the world by utilizing the know-how of the EE educators. This effort requires a lot of practical work and the use of the right approaches (theoretical models).

Fundamental ideas of the engineering education reform in Finland

The public debate shows that the industry needs engineers that operate in the development mode. This requirement directly leads to the new vision for the Finnish EE: there is a need for a qualitative change from the routine mode to the development mode.

Need for an effective unified approach

Because of the complexity of the task, the structural reform of EE cannot be done within a single scientific discipline (e.g. education science). The work demands knowledge and experience in a number of scientific disciplines, fields of engineering, and areas of life. Another reason is that the models of the humanistic sciences are not sufficiently general and unified for this purpose. E.g. education science includes over 20 different models for learning.

For this reason, the work at Stadia has been based on systems and model thinking, which is based on modeling the human being in a systematic way, and the theory of systematic R&D work. The decisive advantage of this unified approach is that it allows all the people active in EE development to work together in an effective way.

Systems and model thinking

The classical scientific approach divides the world surrounding the human beings into a large number of separate scientific disciplines and sub-disciplines. According to systems and model thinking, the world is not divided into disciplines. It is perceived as a collection of functional wholes (systems). The systems approach tries to understand and manage the extreme complexity of the world by treating the world as a collection of functional entities (dynamical systems), which consist of material, energy, and information and by describing these systems with the best models available [8,9,10,11]. In engineering a system is selected as the target of the engineering work. The structure and function of the system is then modeled by means of appropriate models of different forms.

In systems engineering, complex real-world systems are usually described as hierarchical (multilevel) systems. The systems are separated into subsystems. Accordingly, the structure and operation of the systems can be separated to the operational level (how), tactical level (who, what, where, when, how much), and strategic level (why), which is directly connected to the inner goals of the system.

Model thinking

All human life is based on using mental models (representations or "knowledge packages" located in the brain) for describing the world and responding to the events of the world. In addition to these mental models, the humans also use a number of external models (information located outside the brain) for exchanging information and influencing behavior. Examples of the of external models are verbal models (e.g. spoken languages), visual models (e.g. symbols, characters, graphics, still and moving 2-D and 3-D pictures), analog models (system as model for another system), mathematical models (information presented in an unambiguous universal man-made language), and computer models (models of the external models stored and processed in fast electronic form = electronic models).

According to systems thinking, the human beings involved in the EE (students, teachers, specialists etc.) are modeled as complex dynamical, parallel, and hierarchical systems. They have a genetically programmed internal control system, which operates according to the genetic program under the strong influence of the environment and continuously directs the life of the human being towards internal personal goals.

Science, engineering and technology

Science is human activity (work of people) that extracts knowledge from the world surrounding humankind and packages it into useful external models. It is driven by the inherent human curiosity and the need to make the world a better place to live.

Engineering is the human activity (work of people) that improves (mainly) the physical world for the human beings. It is driven by the inherent human creativity and the need to make the world a better place to live. Comparing meteorology to (emerging) weather engineering clarifies the closely intertwined but different orientation of science and engineering.

Technology is the combination of the concrete and abstract tools available to the human beings in this work.

Modeling the human being as a dynamic, parallel and hierarchical biological system

The work at Stadia is based on the modeling the human being as a complex dynamic, parallel and hierarchical (multilevel) biological system [12,13,14]. The latest results of the relevant sciences (e.g. evolutional psychology, cognition science, brain research, neurosciences, and genetics) have been used to compile a unified model for the basic structure and function of the human being.

The fundamental idea is that all humans are survival machines strongly affected by the environment during the whole lifetime. The function of the human (behavior) is driven by an internal control system consisting of two interconnected subsystems. The older one uses unconscious (automatic) positive and negative feelings/emotions and the newer one uses conscious concepts (reason). The genetically programmed system continuously changes and develops during the whole life in close two-way interaction with the dynamic environment. In this approach, learning is understood as the creation of new mental models of the right content and type on the different levels and the removal of wrong mental models. The results of this ongoing work will be published during 2006-07.

Routine work, development work and destructive work

The systems approach can also be used for analyzing the activities/work of people in the society. The fundamental idea of the analysis is that all human beings are equal. They have an absolute human value, which also means the need to care for all people in the society. The level of society can be measured by how it takes care of its members in the weakest positions.

The work people do in the society can be divided into routine (repetitive) work, development (creative) work and destructive work. These three modes of human activity correspond to the three fundamental methods of human survival. They are maintaining the existing environment (system) in its present state (repeating), improving the environment (developing), and removing the threat present in the environment (destroying).

Qualitative differences

There are inherent differences between routine work, development work and destructive work. Routine work is generally repetitive and driven from outside. It uses existing knowledge and skills and lacks the tactical and strategic choices essential in development work. Much of the routine mental work can be automated by means of modern ICT networks.

Development work means bringing a system into a better state through a path, which is unknown in advance. Development work in the real world involves differences of opinion, conflicts of interest, unexpected problems, errors, and temporary defeats. The human rationale for doing development work is the possibility to experience the strong positive feelings produced by the moments of success: satisfaction, pride, empowerment, lightness, warmth, and closeness. Creating new ideas and trying them out is fairly easy for people. Giving up the old is difficult: it creates strong negative feelings, e.g. fear and guilt. All work can be done as development work. It is the attitude to the work that is important.

The inherent characteristics of development work are the uncertainties about reaching the goal (risk). It is caused by the problems and temporary defeats produced by the obstacles during the work. They can be self-inflicted (e.g. lack of knowledge) or caused by destructive people. The situations induce strong negative feelings (mental pain): e.g. disappointment, fear, fatigue, depression, sadness, disgust, shame, guilt, envy, and hatred and bitterness.

The response to the pain caused by the problems/defeats has a decisive effect on the success of the work. There are three basic types of reaction:

-active positive responses: taking care of the problem or turning the problem into benefit/victory (leading to continuing the work)
-passive responses: giving up or fleeing (leading to interrupting the work):
-active negative response): struggle against the obstacle (leading to interrupting or continuing the work depending on the outcome of the response).

These three reactions correspond to the three modes of survival. The first requires conscious thinking and planning. The second and third are usually unconscious reactions that basically correspond to the methods of survival in the animal world: freezing, fleeing and fighting.

Requirements of the three modes

The routine work can be divided to separate parts. Routine work is typically driven from outside of the human. People can also do it alone. In development work, there is a need to understand and handle wholes. Development work is usually driven from inside of the human.

The requirement for routine work is divided work, which is driven from outside, and the repetition of the knowledge and the skills learned once. The requirement of development work is the long-term, systematic and creative, equal cooperation of selected people based on positive feelings. Destructive work only requires giving in to aggressive reactions (”nature’s method”). It can be done by blocking, stifling or destroying. Destructive behavior is easy: there is a very large number of ways to destroy a system.

Successful development work

Development work is demanding in comparison to routine work and destructive work. During the work, the following ”checklist” for successful development work has been compiled:

-responsible (responsibility for own task and for other people),
-goal-directed (destination, dreams, objectives, intermediate objectives),
-planned (short-term and long-term plans),
-persistent (long-term),
-systematic (division to parts, conscious common concepts, logical rules) and
-creative (new ideas, new solutions, crossing borders),
-equal (human),
-co- (personal support group, groups and teams of different sizes, managers, leaders, workers, supporters, processes, projects, networks)
-operation (doing = active action)
-in the real world (not in model world),
-based on positive feelings (enthusiasm, love, hope, compassion, respect, faith, humor) by
-selected (not all),
-internally-driven (committed)
-people (not organizations), who can
-manage wholes (operative, tactical and strategic levels) and possess
-continuously renewed knowledge and skills (mental models) and
-adequate information (external models of different forms),
-adequate resources (money),
-adequate time (key people), and
-efficient tools (concrete and abstract tools, technology) within
-physical,
-environmental, and
-ethical constraints.

The checklist includes 23 items. The list is multiplicative in nature: in case one of the points is missing, the whole is not working successfully. The method has been used for sending twelve persons to the moon and returning them safely to Earth. It is the best-known recipe e.g. for realizing personal dreams, succeeding in business, and solving social problems.

Work in the society

According to the modes of operation and attitudes the active people of the society can be divided into three categories [15]:

1. Developing people = people that are driven from inside positively and bring the society forward.

2. Maintaining people = people that are mainly driven from outside and keep the society going.

3. Destructive people = people that are driven from inside negatively and who obstruct, stifle, and destroy the work of other people in the society.

The division can be illustrated by an analogy to a bus ride: the three groups act as the accelerator, engine and brake of the bus. The valuable passengers of the bus consist of the passive people of the society that are not able to take care of themselves: the children, the sick and elderly people. The importance of the developing people is obvious for the societies in the global competition. Also, developing people are needed to solve the problems of the industry and the society.

The explanation of the division is quite simple. When people try to create new ideas and develop new things, the inevitable problems and defeats of the development work produce strong negative feelings. In these painful situations, most of people consciously or unconsciously react in the passive ways or aggressive ways. This leads to the process, which results in abandoning the development mode. Only a relatively small portion of people continues to act in the positive active way, which leads to the development mode of life. The personal choices result from the combined effects of genetics and the environment. The division to the three categories is also present in all organizations and groups of people.

Change in organizations

Development work is done by individuals, not organizations. Organizations, however, have a decisive effect on the success of development work. Organizations can facilitate or hinder the work of the developers.

The mechanism for changing/developing groups, organizations and societies is relatively simple. First, a creative human being sees a need for development or a problem to be solved. Then he/she starts to solve the problem (do active work). After some initial success, other people interested in the results and outcomes join the work. In this way, an increasing group of people is formed. Over time, the people working in the new way gain a majority. Finally, the resisting people join because they have no other choice. The most important thing in the process is to give the developing people the freedom and resources needed in the work and support them concretely, particularly during temporary defeats and against destructive people.

Analysis of the current engineering education in Finland based on systems and model thinking

There are no simple solutions for the problems of EE. Therefore, a detailed analysis of the current EE is needed. The basic idea of the analysis is that real learning and teaching is development work, not routine work. The presentation of the prepared material to students is routine work (transparencies). The regurgitation back to the teacher of the material presented by the teacher or read from a book in a test situation is also routine work.

Changes on the relevant hierarchical levels

Changes of the society of Finland during the past decades have directly influenced the higher education of Finland. During the 1990s, the education system of Finland has undergone great changes. The first is the shift from elite to mass education. In Finland, national plans call for over 60% of the annual age group to be educated to the tertiary college level. These changes have also led to increased competition between EE organizations for high-quality students and faculty.

The expansion of higher education raises the average know-how level of the country and affects the characteristics of the students. Present-day youth no longer follow the classical ideologies or conventions of the societies. At the same time, the students are strongly influenced by advertising and media.

The Finnish youth no longer has the historical economic and social motivation for higher education. In a way, Finland has reached its goals: the basic physical and mental needs of the youth are satisfied. This has also changed the status of higher education: the youth do not see it as the only way to success in life. These changes have had a distinct effect on the know-how level and they have increased the heterogeneity of the students entering EE. Therefore, the new requirements can only be achieved by embracing the individual motivation on the highest levels of the human behavior (creativity).

The situation during this decade places new demands on the EE organizations for deeper learning, more efficient and innovative teaching, more responsibility for student employment and career success, and responsibility to society. In the field of education, the transition to the development mode is still at its infancy. The profound changes in societies and the dramatic developments of technology have had relatively little effect on the structure of the EE. Most of the current EE organizations and programs have been implemented in slowly changing routine societies (e.g. army, Taylorism, Industrialism). The current EE model is based on the classical education structure, which has evolved (not systematically developed) for a static society over a number of centuries. The curriculum of most EE institutions in the world goes back to the curriculum implemented in the USA in the late 1940s.

The structure has been maintained even when the complexity of the world has increased and the technology has changed dramatically during the late 20th century. The mode and organization of EE institutions still correspond to the industrial era (assembly line) mode. The structure of the current EE is intrinsically based on the division of the world into specialized disciplines and subjects. The curriculum is partitioned into separate courses and the learning is controlled by means of individual written tests. This has led to a fragmentation of the content, the work of people involved, and their use of time.

Most of the content presented is based on the model world e.g. textbooks and theories. This separates the learning from the real world (e.g. work of the engineer). The emphasis of the present EE is on quantity, aiming at including and presenting everything an EE student needs during his/her career. This way of doing things has led to overloading and incoherence and the lack of the ability to combine knowledge into functioning wholes in the real world.

The fundamental reasons for the deficiencies of the present EE is the underlying conscious or unconscious model for the human being, most importantly the student. In the current EE solution, the model for the human being is a physical (nonliving) object. The student is regarded as a container, e.g. a partially filled cup, or a machine or computer. The goal of the present EE model is to fill all students with a similar knowledge to last their whole lifetime. The teachers are understood mainly as dispensers for filling the cups.

It is important to realize that the current situation is not due to the deficiencies of the educators or the teachers. In fact, the present model has become a barrier for individual teachers for improving their work, making it impossible for the teachers to meet the new demands.

Fragmentation of the mode of operation, structure and content of EE

Because of the geographic spread in Finland there are too many institutions and programs. On the other hand, the free EE offered in all parts of Finland is a great benefit for Finland. It creates equality and makes it possible to utilize the talent of the 5.2 million people of the country.

To summarize, the current EE can be described as an outside-driven fragmented mass teaching in the model world. It is divided into scientific disciplines with different concepts and terms, subjects, basic and professional subjects, and courses, and relies on personal examinations for grading. The inherent structure directs the students and teachers towards the routine repetition mode, working alone, and using the time and resources ineffectively. The practical example is that when a new need is detected, a course is added to the curriculum. For example, if there is a need for learning ethics, a course in ethics is added.

The fundamental reason for the fragmentation is that the knowledge and teaching/learning needed to achieve the professional level of the engineer ("engineerness") is first differentiated and then integrated. As an example, project learning and ethics are taught separately, not built in to the intrinsic operation. Deeper reasons underlying the problems and deficiencies are the confusion of the real world and the model world, confusion of science, engineering, and technology, and the use of an incorrect simple model of the human being.

Fragmentation of the operation of EE organizations

The basic responsibilities of the EE organizations in Finland are teaching, research and development, university-industry cooperation, life-long learning and regional development.

In the current situation, the EE organizations still operate in the routine mode. At the same time, separate parts from the new development mode are being added. As an example, the faculty members have more than 20 tasks: e.g. basic BS teaching, R&D work, university-industry cooperation, regional development, development of teaching, development of new programs, international operation, MS teaching, life-long learning, further and continuing education/professional development, development of own field, deployment of new technology, mentoring and tutoring, initial training of new teachers, further education and continuing education of the teachers, exchange of teachers and industry, recruiting and career services, innovation work, support of entrepreneurship, alumni cooperation, strategic planning, quality methods, and internal and external assessments.

This situation, where new tasks are added and old ones are retained, has increased the number of simultaneous tasks and the total workload of the faculty and staff. It has decreased the motivation and placed strong demands for preventing the excessive fatigue of the teachers. The problems are accentuated for the experienced teachers taking part in development work.

Conclusions based on the analysis

The mode of operation, structure, content and organization of the current EE are based on the former assembly line mode of the industry (Taylorism). This routine way is based on repeating what has been done earlier and what others are doing. A part of this is that EE is still based on the division to disciplines and subjects while the companies are operating by using modern quality management methods by using processes and projects. This approach is also based on the systems approach: industrial and business operations are not divided into scientific disciplines. Systems thinking is the natural basis for all work that takes place in the real world. The idea of continuous improvement is also compatible with the systems approach.

These fundamental differences create a discrepancy between the EE organizations and companies: the modes of operation are structurally and qualitatively different and the ways of thinking behind them are qualitatively different. For this reason, the new engineers for the 2010s and 2050s cannot be trained by organizations operating in the old mode.

Need for restructuring

The inherent structure of the current EE inhibits the change of the EE institutions needed for meeting the demands imposed by the society and the industry [19]. The industry is the main customer of the EE organizations. During the past decade it has also become clear that the discrepancy between the education organizations and their corporate customers can no longer be solved by means of partial solutions within the present operating mode: e.g. adding subjects, courses or projects, adopting new teaching methods, and exploiting new technology.

The disparity between the new requirements and the deficiencies of the present EE has created a strong need for the restructuring of the EE. During the early 1990s, the need for a major change in EE has been emphasized in Europe and the USA [18.] At the same time, dramatic advances of ICT offer great possibilities.

Result of the analysis

The understanding of the conflict between the current EE logically and the industry leads to the conclusion: the situation can only be remedied if the EE institutions make a rapid structural change from the routine mode to the development mode. Because of the similar structure, this analysis for EE also corresponds to other higher education. Because of the nature and role of engineering profession, EE is a natural pioneer for other higher education and academic education.

Analogies for the R&D work

For the purpose of developing a new EE solution, an EE organization can also be regarded as a customer-driven service company and the EE provided by the organization as a service product, which has multiple customers. The analogy of an EE organization to a company, however, has deficiencies. Most physical products are entirely passive. Many service products also require little activity from the part of the customer. Learning, however, depends decisively on the active long-term participation of the student in the learning process. Therefore, students can be considered as the clients (active long-term cooperative customers) of the EE organizations. The industry, that hires the young engineers, can be regarded as the customer of the EE organizations.

In the R&D, the analogies between EE organizations and companies can be used [20]. The most important ones are the modern ways of thinking and work methods. They include group and team work, total quality management, just-in-time operations, supply chain management, time based management, lean management, mass customization, modularization, outsourcing, concurrent engineering, activity based management, business processes reengineering, and systematic benchmarking.

Development of new engineering education as Stadia

The new EE model developed in Finland is based on the definition of the competence requirements for the engineer working in the global environment. These requirements can be summarized as the capability to do efficient engineering work in a selected engineering field in the international environment and to have a successful engineering career. The emphasis of the goals is on learning the engineer's systematic and creative way of thinking and doing things in the real world. The goal of engineering is to make the world better for the human life. An engineer is a doer: at his/her best the engineer "continues the work of nature".

Use of learning projects as the basic solution

The main building block of the new model is a learning project connected with the real world. It is a task performed by the student selected and formulated to produce required learning. The needed learning is "built in" into the learning projects. A learning project is divided into learning tasks.

The themes and contents of the projects are selected, formulated and coordinated to meet the learning goals: the learning goals are imbedded in the learning projects. A sequence of learning projects is used as the vehicle for creating an effective learning environment for supporting and guiding the student's individual learning processes during the whole study period.

The sequence starts with relatively small-scale learning projects and approaches real-time projects from the industry/society during the study period. Participation in a real engineering project during the first year gives an important foundation for the following years. During the second semester the students use approximately half of their time to carry out an industrial project from a partner company/organization. Individual learning projects are included in the project sequence during the whole learning period.

A process of learning projects running throughout the total learning period concentrates on the work of the engineer. It helps students to grow into engineers by describing the fundamentals of the engineering profession and providing real-world examples. Seeing a picture of a jigsaw puzzle greatly facilitates the assembling task.

The task of the faculty is to assist and support every student in developing into an engineer. This is done as an equal cooperation, which uses all the methods of successful development work (e.g. group, team and project work). Experience shows that the first year is the most important year, requiring the teachers with human skills and deep understanding of engineering.

Difference of courses and learning projects

The aim of a course is personal learning. The aim of a learning project is to accomplish something in the real world. The results and outcomes of the learning projects can be very small, particularly at the beginning of the studies. The most important thing is the mode of operation and the attitude. The idea of a learning project is that doing things in the real world gives the young students and the teachers inner motivation and positive feelings.

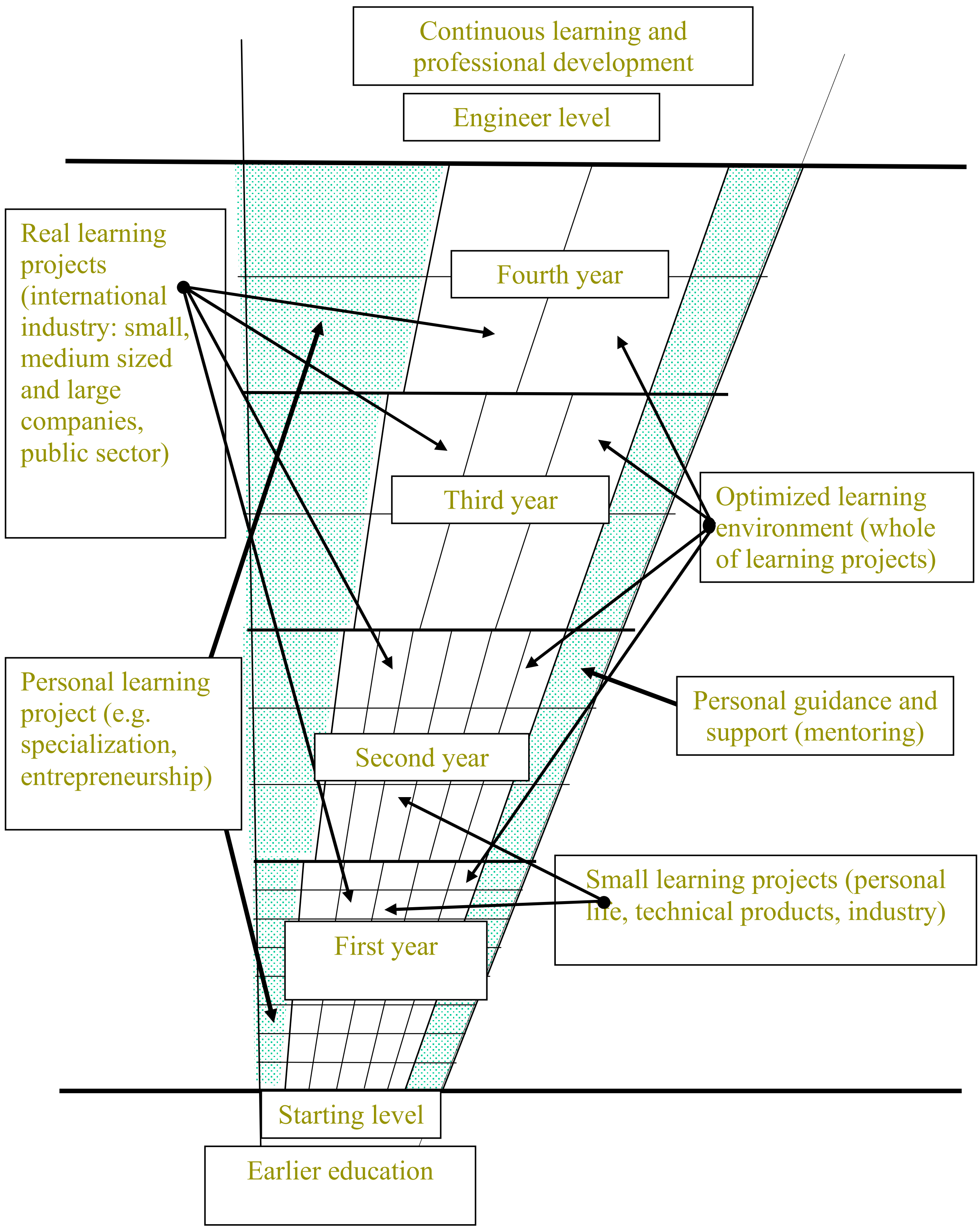
Details of the learning project sequence

The learning projects form a whole, which during the study period leads to the ”engineerness” required by the modern international industry. The learning projects are different and have different forms. During the study period, the learning projects grow and develop during the whole study period. Examples are projects connected with the personal life of the students, media events, achievements of engineers, development projects of the teachers and faculty members, projects from partner companies and organizations, practice/internship, study periods abroad, personal specialization, entrepreneurial projects and the thesis work. Also the projects from industry are learning projects: the themes and content are selected in the way, which allows the learning goals to be achieved. Also, international operation is naturally built into the whole. At the pilot program of Stadia, some of the learning projects are international and the third year is an international year taught in English.

Optimized whole of the learning projects

The new kind of EE model provides the flexibility for selecting and formulating the learning project sequence together with the local industry. This optimization is based on a direct feedback from the students, teachers and industry. During the design and implementation, the project sequence is continuously optimized on the project level and the sequence level by selecting, formulating and coordinating the themes and contents of the projects. This method is consistent with the “meet in the middle” approach in systems engineering, which combines the details (operational level) with the whole (strategic level) on the middle (tactical) level.

NEW ENGINEERING EDUCATION SOLUTION



Structure of new engineering education

The new EE model resulting from the work in Finland can be summarized as a shift to inside-driven, individual total learning in the real world. The new approach places the main emphasis on the individual learning processes of the students. This mode of learning can be defined as "learning by doing, accomplishing and experiencing". In the new model, this type of learning is intrinsically embedded in the mode of operation. The sequence of learning projects leads to the learning goals for the engineer derived by the EE organization in cooperation with industrial partners. The main mode of operation is the systematic and creative long-term cooperation of the students and the teachers/specialists on an equal human level.

Systematic cooperation

All the practical forms of cooperation of successful development work are used in the learning and the cooperation between the students and the faculty. As an example, the students start their work in groups of three students during the first semester. They also work in larger groups and project organizations during the industrial project during the following semesters. The experience shows that continuous change of groups and group characteristics is needed during the whole study period.

In a similar way, team and project organization is used for the cooperation of the teachers. Each learning project has a project manager who manages and coordinates the work of the faculty and staff members assigned to the project within the resources allocated.

Continuous feedback and control

The experience during the development of the new model has shown that the individual learning processes of the students must be measured in real-time. The measurements are performed e.g. by compact individual tests built-in to the learning projects at the beginning and during the projects. These tests are designed to measure the understanding and use of the fundamental scientific and engineering concepts and models in the real world. The on-demand lectures ("information flashes") during the projects also concentrate on these basics. The tests can be automated by using modern ICT systems.

The grading of the students is based on the outcomes of the learning projects, which corresponds to the nature of the engineering profession. Most of the outcomes are group outcomes but they also include individual outcomes. The systems and model thinking approach makes it possible to design these tests and outcomes in a systematic way in comparison to the current fragmented approach.

The personal tests and outcomes positively force the students to work on a weekly basis. They make it impossible for them to advance through the program in the superficial learning mode (concentrating only on passing the examinations), which is common in the current EE. The continuous monitoring also has the advantage that it tells the students what the basics are and forces them to understand and use them. This is important because the students are not professionals: they do not yet have the inner knowledge structure (general mental model) of the professional engineer.

This type of continuous real-time feedback integrated into the learning projects also makes it possible to guide and support the students on the on-demand basis. It forms an essential foundation for the effective cooperation between the students and the teachers. The main objective is to maximize the personal contact of the experienced teachers with the students, which produces most of the deep learning (added value) in EE.

Real-time teaching

The new way of doing things converts the work of the teacher from presenting his/her subject matter to making the students learn the required knowledge and skills in cooperation with other teachers. It frees the teachers from most of the routine presentation of information and makes them coaches (leaders or mentors) for the students. The new model also has the flexibility for choosing the tasks of the teachers and faculty according to their personal skills and interests.

As part of the new model, the basic knowledge needed in the learning projects is made available to the students as effectively as possible. The main method is to give compact lectures ("information flashes") for the whole student group. These on-demand lectures are driven in real time by the requirements of the projects. They are given by the faculty members or outside specialists participating in the learning project.

Because the learning projects are not divided into subjects (as real-world engineering projects) the effective lectures typically include information from multiple classical disciplines/courses. The "flashes" also include examples and basic exercises that make it easier for the students to understand and carry out the projects.

The "flashes" are delivered during the weekly slots allocated to the project. The timing decisions are based on the direct feedback from the teachers and the representatives of the student group. In practice, this is done in weekly faculty/staff meetings where the student representatives participate. The on-demand lecturing increases the motivation of the students and teachers and increases the effectiveness of the new model. In addition to the lectures, selected material in books and on the Internet is also included in the project material. The multiple methods used in teaching correspond to the different learning styles of the students.

Counseling and mentoring

The continuous process also contains a personal mentoring system. Selected teachers of the student group, interested in the human being, function as a team of mentors. Mentoring is based on personal contacts with the students and on real-time feedback through the feedback system. This arrangement allows the mentor to support the student in case of difficulties and temporary problems. The mentoring effort in concentrated to the first and last year, when the need for the personal support is greatest.

Assessment and grading system

The assessment system integrated into the new structure is divided into two components: the system for self-assessment and the system for grading. Self-assessment is continuously used to evaluate the learning processes of the students by providing direct feedback from the teachers and fellow students as natural part of the cooperation. The second component for the individual grading of the students is based on the evaluation of the individual outcomes of the learning projects. The students present the outcomes of the learning project to a teacher as a justification for their grades. The evaluation also includes private and public personal discussions between the teachers and the students. These meetings take place during the learning tasks and at the end of the learning projects. They also provide the personal feedback, which has been found to be very valuable to the students.

Learning of ethics

Experience at Stadia has emphasized the importance of the ethics of the students and teachers. The new way of doing things requires the students to take responsibility for their own learning. Importantly, it also forces the students to take responsibility for other students participating in the team work. In this way the learning of ethics is built in to the new EE.

Role of modern information and communication technology as a strategic tool

Modern ICT is used as a central tool in the development of the new EE solution. It is systematically used for the automating the routine part of the work. This includes e.g. the delivery of basic material to the students, weekly and daily scheduling, and the practical arrangements for the grading of the students. Experience has shown that modern ICT is the only way to control and coordinate the complex operation and organization of the new EE.

Because modern ICT is a very effective modern tool the benefits cannot be achieved by adding technology to the present operations. In order to obtain the benefits, the organization must learn to do things in a new way and to change the structures and modes of operation accordingly. In the new EE solution, this has been done: it uses the most modern ICT in its proper role as a decisively important strategic tool. The new model cannot be realized without the modern ICT. The reason is that it is based on the extensive and complex cooperation of people in many forms (checklist of development work). The information system frees the time and energy of the faculty for the most important task: personal contact of the faculty, staff, and specialists with the students.

Practical operations

On the strategic level, the common information system is used to form the goals of the people participating in the operation and directing them towards them. On the tactical level, it is used to coordinate the cooperation of the people. On the operative level, the system is used to automate the repetitive routine work (transferring the work to machines) and directing the practical work of the participating people (e.g. doing the learning projects).

In practice, the work is carried out with the assistance of an easy-to-use information system. The center of the system is the common web page (“home”) of the program, which all the people cooperating can access from anywhere in the world. The modern Internet allows the students and teachers to cooperate by even using real-time audio and video communications. The system is used by means of workstations, laptops, and wireless terminals. The students of the pilot program are given a personal laptop at the beginning of the studies.

Comparison with current EE model

Because the world is inherently interdisciplinary, there are no divisions to subjects and courses or to basic or professional subjects. The use of learning projects connected with the real world removes the need for integration because the projects are not differentiated to disciplines or subjects. The content needed for obtaining the learning goals can be embedded into the learning projects in a natural way by selecting and formulating the themes and contents of the projects.

The new way of implementing EE is the same than that of the international companies. The explanation is that the new mode of the EE organization corresponds to the development mode of the modern companies.

Integrated engineering education

By using properly selected and formulated learning projects the functions of the EE organization can be integrated in a natural way.

1. Basic undergraduate teaching, R&D work, and cooperation with industry can be carried out by selecting suitable learning projects taken from teachers, EE organization, and partner companies as part of the project sequence.

2. Graduate education and life-long learning and professional development can be integrated into the whole process by using learning projects taken from the industry. Experienced adult learners can function as learning project leaders and use theoretical approaches and models as effective tools.

3. Support for entrepreneurial activities can be included by selecting projects from the start-ups of the students or from other start-ups in the region.

4. International operation can be included by means of an international network of selected universities and long-term partner companies.

5. Continuing and further education of the teachers can be integrated into the planning and carrying out of selected learning projects.

6. Faculty-industry exchange (e.g. sabbatical) can be integrated into the sequence. E.g. by using outside funding the teachers can be freed for important R&D projects in the partner companies.

7. Close long-term cooperation with industry facilitates recruiting active high-level teachers.

8. Efficient overall process of real-world learning projects automatically leads to effective regional impact.

Experiences of the R&D work at Stadia

The experience of Stadia has shown that the adoption of the new model is a very demanding and difficult change. The theoretical approach underlying the work is mainly needed during the development phase. During the operation phase, the emphasis is on the themes and content of the learning projects, on the whole formed by them, and the cooperation of the participating people. The reform can only be realized through close cooperation of the people involved and the strong support of the leadership.

The qualitative change can be realized only by giving up the current way of doing things. In the work at Stadia ”the dearest things” of the current model - division to disciplines, subjects, basic and professional subjects, outside-driven lectures and the personal paper examinations - have been abandoned.

Cooperation with industry

The work at Stadia has also shown that the only possibility to achieve the new learning requirements is the active long-term cooperation between EE organizations and industry. The cooperation gives the students an opportunity to get acquainted with their future work environment. It also solves the motivation problems of the students and leads them to real cooperation with the teachers and specialists. The experience of Stadia has demonstrated that this type of cooperation cannot be based on the personal contacts of the faculty members with industry. Long-term systematic cooperation can only by achieved by implementing a mutually rewarding partnership system on the university and, later, on the national level.

Systematic cooperation of engineering education organizations and industry

The long-term partners of EE organizations can be large corporations, SMEs, and start-ups, including the companies of the alumni. These companies would search for suitable tasks in their operations and offer them to the partner EE organizations. In this way, the EE organizations continuously receive a stream of learning projects of different forms for the whole learning period.

The companies also partly compensate the costs to the EE organizations, which use the additional resources for the planning and realization of the real-world projects. Also, the representatives of the enterprises participate in the EE as managers of the learning projects, managers of group and teamwork, and as mentors. They also deliver some of the on-demand lectures. The alumni of the program are very important because they know the program accurately. The cooperation requires rules and agreements, which minimize the risk of both parties.

This type of close university-industry cooperation can be extended to other fields, e.g. common education and training. The new form of cooperation can also be financed by the institutions that supporting innovation and local entrepreneurship

Benefits to partner companies

The basis of the system is that the learning projects directly benefit the partner companies e.g. in the form of development projects or creative projects. Through the projects, the companies gain access to the manpower, expertise, and creativity of the students and the teachers.

The cooperation offers the partner companies a unique opportunity for selecting a young engineer during the studies by using the company learning projects as a tool. This gives the companies a possibility to assess the young engineers in real work conditions during a relatively long period of time (not just during a recruiting event) and select the most suitable young engineers. The companies can recruit the engineers in a natural way and minimize the costly recruiting errors. This mechanism also makes the engineers immediately productive for the companies. A pilot system will be implemented at Stadia in other EE institutions in 2006-07. Later, the system can be extended to the national level.

Potential advantages of the EE reform

For the EE organizations adopting the model, it would provide benefits in the competition for high-quality students, faculty, and staff, and lead to more efficient utilization of resources, including the know-how and creativity of the people of the faculty. The new mode of operation combines the government-assigned tasks of the university in a natural way.

For the faculty members/teachers, the model makes the work more rewarding and enjoyable. It naturally directs the teachers towards cooperation and becoming coaches/mentors/leaders and enhances continuous professional development.

For the students, the new EE model offers more effective and rewarding learning and real personal electiveness. The internally-driven process naturally enhances the self-knowledge and personal strengths of the students, directs the students towards employment or an entrepreneurial career, and forms a natural start for a successful career in engineering.

The new model is also applicable to continuing EE, continuous professional development, and other fields of technical education. The restructured EE represents an example of the fundamental reengineering of professional and academic education for meeting the new needs of the societies in the global environment.

Advantages for industry

The new model eliminates the discrepancy between EE and modern work life. In practice, this means that the young engineers studying in the new way can not graduate without having the fundamental skills needed in modern engineering, e.g. cooperation skills (group work, teamwork and project work and international skills. These important skills cannot be taught in the current way e.g. by adding separate courses.

For the industry, the immediate benefit of the new way of doing things is that it will provide the companies with higher-quality engineers that meet the new requirements with ”young engineers with the latest know-how and skills and a long experience in industry”. These engineers are immediately productive to the companies and very valuable for the companies operating in the international markets.

The goal of the new EE is to improve the problem solving capabilities, confidence, responsibility, innovativeness, creativity and entrepreneurship of the students. The young engineers, therefore, are better suited to creating new technical solutions, new products and services, and new business. The most decisive benefit for the industry in the 2010s, however, is that the EE studies realized in the new way attract more of the most talented and active students of each age class to EE and allow the most talented teachers (people living in the development mode) to be recruited for them.

Advantages for the nation

The new EE model naturally directs the EE institutions towards producing innovative people for the benefit of the nation. It is an example of how the higher education system can be changed to direct the talent and energy of the youth to benefit the future of the nation.

Implementation in Finland

At Stadia the emphasis of the R&D work to be continued with the industry support during 2006-07 is on expanding the use of the new model within the Faculty of Engineering, improving the use of resources, obtaining additional resources, and starting the long-term cooperation system with industry. The people with experience in the original development work would participate in the expansion. The work would include teacher education in the theoretical fundamentals: e.g. systems and model thinking, structure and function of the humans being, and development work.

The experience of Stadia indicates that the most natural place for implementing the new solution would be the highest-level education in selected EE programs in Finland. It would then be expanded to other EE programs interested in EE reform. The implementation is limited by the availability of suitable faculty and staff members who have the knowledge and skills needed in the new EE.

Another important starting point would be the reform of the first year of EE. The first year could be common to all departments. It could be partly adapted to the fields the departments by the themes and contents of the learning projects. The new way of starting the engineering studies would naturally support the students in making their personal choices during the second year. This type of a unified first year would offer savings and solve many of the problems of the current EE.

Implementation in an engineering program

Because the implementation of new model is a demanding task, the natural way is to start with a single student group. According to the theory of development work, the planning and pilot testing would be carried out by committed faculty members. Teachers with experience in engineering and interest in deep learning would be selected as learning project managers. They would form the planning group that would develop the learning goals, create the learning projects, and prepare the material for the projects. The same people would teach the pilot group in cooperation with assistants and specialists. An experienced project manager is needed for managing and steering the work. Over the years, the pilot operation would be expanded to other student groups as new committed faculty members become available.

The reform of EE is a demanding long-term process, which requires the special attention and support of the director of the program, the dean, and the university management. The active involvement of the industry, the professional engineering institutions (e.g. ABET), and the government would be needed to accelerate the transition on the national level.

Resources

The development and implementation of new model in cooperation with the industry requires more resources than the current basic education. Part of the additional resources can be obtained by combining the resources that are wasted in the present fragmented operation. Additionally, the reform of EE in Finland during the 2010s will require a long-term investment by the Finnish government in the form of separate development funding and increased funding for the EE institutions operating in the new way. This corresponds to the proposals included in the final report of the Committee for the Development of Technical Education and Research in Finland submitted to the Ministry of Education in August 2005.

Example of using the systems approach for bridging the gulf between engineering and human sciences

The reform of EE described in this article is an example of how the neutral systems approach can be used as a vehicle for bridging the gulf between engineering and the human sciences. The new approach used can be regarded as the extension of the engineering approach from physical systems to the realm of the more complex social systems consisting of people. It requires a unified composite model for the structure and function of the human being. By using system and model thinking and the latest results of the relevant sciences (e.g. evolutionary psychology, cognitive science, neuroscience, biology, and genetics), the human being can be modeled as a dynamic, parallel, and hierarchical system.

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