On a Frame Work of Curriculum for Engineering Education 4.0

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***Abstract*— The fourth industrial revolution, named as, Industry 4.0 encapsulates the industrial productions oriented towards an intelligent cum autonomous manufacturing process, that in turn, depends upon cyber physical systems, design cum development of cyber physical production systems whose operations are monitored, coordinated, controlled and integrated by a computing & communication core. So, for an effective implementation of Industry 4.0, Engineers should have expanded design skills that cover interoperability, virtualisation, decentralisation, Real time capability, service orientation, modularity etc. along with the information technology skills. So, Engineering Education which generates engineers for Industry 4.0, referred as Engineering Education 4.0 (EE 4.0) should get transformed to meet the demands of Industry 4.0, that stresses the integration of all the engineering disciplines. Instead of the present discipline-dependent curriculum, this paper proposes a discipline-independent framework for the curriculum of EE 4.0, in which all the engineering disciplines gets amalgamated, to generate a unique discipline called Engineering 4.0. Every Engineer who comes out of the proposed curriculum will have the basic skills of all the disciplines, social responsibility and professional ethics. Learning outcomes, measured in the usual way with the standard tools , are mapped with the skill-requirement of industry 4.0.**

I. Introduction

The words of Albert Eienstein, "The development of general ability for independent thinking and judgement should always be placed foremost, not the acquisition of special knowledge. If a person masters the fundamentals of his subject and has learned to think and work independently, he will surely find his way and besides will better be able to adapt himself to progress and changes than the person whose training principally consists in the acquiring the detailed knowledge" makes it clear that the main objective of education is to prepare the graduates for work and life. With this idea, one can define the education as a process that integrates Humanities, Science, Technology, Engineering,Art, Mathematics, Medicine (HSTEAMM) at the undergraduate level, associated with the increased critical thinking abilities, higher order thinking, deeper learning, content mastery, creative problem solving, teamwork & communication skills. The integration of HSTEAMM is stressed in the consensus report on education published by the National academies of Sciences, Engineering and Medicines[1]. This process can be achieved through acquisition of knowledge, skills & competencies related to the profession one chooses, communication skills, ability to work as a team, ethical decision making, critical thinking, ability to apply knowledge to solve real-world problem.

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A. Engineering Education

Having described the process of education, we now turn towards Engineering Education, which is the main focus of this paper. It is better to define 'Engineering Education' in a proper perspective, since this definition alone will serve as the objective of Engineering Education, in the process of implementation. Many policy documents, right from Mann Report in 1918 till 'Engineers of 2020' in 2004 [2], provide a glimpse of the definition of Engineering Education, where the focus is on understanding how engineering definitions change over a period of time.

Like Moore's Law, scientific and engineering knowledge doubles every ten years [3], which is evident from the rate at which a technology gets introduced, adopted and cease to exist. Many product cycles continue to decrease & each cycle delivers more functional and often less expensive version of the existing product, with the existing cycle paves way for an entirely new 'disruptive technologies', thereby making the older technologies obsolete at an increasing rate. In other words, Engineering education is in a piquant situation where we have to make our graduates ready for the future jobs that don't exist now, using technologies that have not come up, to solve the problems we do not know are problems yet. The notion that a person learns all that one needs to know in a 4-year programme on engineering is not at all true by any means and never it was. Even the fundamentals are not getting fixed.

At its core, 'Engineering' is the skill of applying scientific as well as mathematical principles to design, develop and operate, structures/machines/materials/ systems/software, as well as maintaining them, to address a particular challenge for a particular purpose . The so called 'particular purpose' in the earlier line, should be instrumental in developing the society. Only this observation prompted Ken Lutchen of Boston University, to call the engineers as 'societal engineers' to bring out the social responsibility of the engineers, who have a sense of purpose to the extent that engineering education forms a superior foundation for improving the society. Societal Engineers can influence the real world not only in engineering and technology innovation, but by pursuing management, finance, government, medicine, law or any another profession where their engineering backgrounds provide the foundation needed to improve society.

Considering all the above, the main attributes of expected from an engineer are strong analytical skills (problem solving skill), creativity, practical ingenuity, communication, business & Management, global awareness, leadership, dynamism, resilience, flexibility, ethical standards, professionalism , social consciousness, Public policies.

B. Industry 4.0

The term Industry 4.0 was first publicly introduced in 2011 as Industrie 4.0 by a group of representatives from different fields (such as business, politics, and academia) under an initiative to enhance the German competitiveness in the manufacturing industry. Industry 4.0 refers to a new phase in the industrial revolution that focuses heavily on inter connectivity, automation, artificial intelligence and real-time data. Industry 4.0 is not just about investing in new technology and tools to improve manufacturing efficiency. Its about revolutionizing the entire business operation oriented towards growth.

The first three industrial revolutions focused on mechanisation, electricification and automation with computers respectively. Industry 4.0, called as fourth Industrial revolution, encapsulates the industrial productions oriented towards an intelligent cum autonomous manufacturing process that in turn depends up on cyber-physical systems, design cum development of cyber-physical production systems,smart factories etc. Industry 4.0 is the evolution to cyber-physical systems, representing the fourth industrial revolution on the road to an end-to-end value chain with Industrial Internet of Things (IIOT) and decentralized intelligence in manufacturing, production, logistics and the industry. Here, Cyber Physical Systems (CPS) are physical systems whose operations are monitored, coordinated, controlled and integrated by a computing & communication core.

Industry 4.0 takes the automation of manufacturing processes to a new level by introducing customized and flexible mass production technologies.This means that machines will operate independently, or cooperate with humans in creating a customer-oriented production field that constantly works on maintaining itself. The machine rather becomes an independent entity that is able to collect data, analyze it, and advise upon it. To say, under Industry 4.0, production assembly-line will no more be sequential; production may involve many number of work-stations which will communicate with each other, intelligently decide among themselves the task to be carried out , so that, at the end, all the work-stations collectively accomplish the product in a more cost-effective, optimised way, which will accelerate the business performance. This is made possible by introducing self-optimization, self-cognition, and self-customization into the industry. The manufacturers will be able to communicate with the machines rather than operate them.

Till Industry 3.0, Physical systems (products) were designed and deployed individually so that the products function independently. As mentioned, in Industry 4.0, Cyber Physical Systems which are governed by the three C's (Communicate, Compute and Control) require the systems to have the provisions for a transparent communication between any type of systems (be it physical/software) etc. In that sense, the design of Cyber Physical Systems in Industry 4.0 should have some more stuffs than the usual design in engineering, to accomplish the things like: connecting the machines digitally, communication between machines, autonomous decision making by the machines etc. Thus, the existing engineering education which caters to the requirement of the usual industry, needs to expand its domain to upgrade it to meet the demands of Industry 4.0.

The Engineering Education which generates engineers for Industry 4.0 (referred as Engineer 4.0), referred as Engineering Education 4.0 (EE 4.0), should get transformed adequately to meet the future demands of Industry 4.0.

Thus, Engineering Education 4.0 should represent one of the most challenging themes for engineering design for Industry 4.0 . At this moment there are a few studies in the field of engineering education that investigates how the educational needs of students and of the industrial workforce are changing. On this basis, this paper makes an attempt to investigate on the necessary skills and expertise young engineers should acquire to be ready for the Industry 4.0 framework. In that regard, our exploration revealed that almost all the skills required for Engineers 4.0, are not confined to a single discipline of engineering like mechanical engineering or electrical engineering or computer engineering. All skills are cross-disciplinary skills which involve all knowledge-domains of the all the existing disciplines of engineering. Instead of the present discipline-dependent curriculum, the cross-disciplinary nature of the skills required for the Industry 4.0, motivated us to propose a discipline-independent framework for the curriculum of EE 4.0, in which all the engineering disciplines gets amalgamated, to generate a unique discipline called Engineering 4.0.

This paper is organised as follows. Section 2 discusses the requirement of Industry 4.0 and the necessary skills that should form part of Engineering Education 4.0 and a proposal of the discipline-independent framework for the curriculum of EE 4.0. Section 3 correlates the learning outcomes of the proposed curriculum of EE 4.0 with the skills that are required for Industry 4.0. The paper concludes with the possible advantages and the possible limitations of the proposed framework for the curriculum of EE 4.0

II. Engineering Education 4.0

In this section, we discuss about the skills and competencies required for the Engineering Education 4.0. 'Engineers of Industry 4.0', must learn the skill of applying scientific as well as mathematical principles to design, develop and operate, maintain, integrate, inter-connect, control & analyse the structures/machines/materials/systems/software. Thus, Engineering Education 4.0 is the process of developing such skilled professionals,

As discussed earlier in Section 1, so far, machines for a specific functionality were designed and deployed individually so that they function independently. But, in Industry 4.0, machines are connected digitally and are governed by the three C's (Communicate, Compute and Control) which require the systems to have the provisions for a transparent communication between the systems (be it physical/software). Then, we get many questions like : how does two machines communicate? If the communication is through sensors; where, in the machine, one has to embed the sensors?; where does the data captured by the sensors stored?; How and where does the computation with the data received from the machine happen? How does the machine take a decision based on the computation? etc. The above questions make clear that, the designer of a machine in Industry 4.0 has to take care of all the above issues, which covers the knowledge of the various domains[8] such as :design, communications engineering , computation engineering, control engineering, the collection of data, analysis of the data, decision-making from the data etc. In that sense, the basic design principles of engineering for Industry 4.0, gets expanded to cover the features such as : Interoperability, Virtualisation, Decentralisations, Real-time capability, Service Orientation, Modularity etc. Besides, since most of the above features are based on connectivity through Internet of Things and communication of information (data) through IoT, Industry 4.0 has to face the IT security issues, reliability and stability of machine to machine communications (M2M), Integration of the production systems, Safety standards of CPS etc. So, for an effective implementation of Industry 4.0, we require engineers with expanded design skills apart from the Information Technology skills.

In short, Industry 4.0 era necessities new cross-functional roles with different knowledge and skills that combine IT and production knowledge. The academia has a vital role in fulfilling this need in understanding the characteristics of knowledge and skills provided in these functional roles and impart the same to the future engineers. In other sense, Engineering Education 4.0 should focus on the competencies that lead to digitization of the manufacturing sector, with embedded sensors in virtually all product components and manufacturing equipment, ubiquitous cyber-physical systems, and analysis of all relevant data (McKinsey & Co., 2015).

A. Functional Domains of EE 4.0

Based on the above discussion and the objectives of Industry 4.0, The functional domains of Industry 4.0 can be listed as follows with their related functionality:

- **Designing CPS :** Study, design, develop, operate, maintain an integratable, inter-connectable structures/machines/materials/systems called Cyber Physical Systems.
- **Modularity:** Machines are built from sub-systems that can be combined in different ways to perform a range of desired functions. This can save a lot of time in the planning, design, and commissioning of such machines, as well as enabling rapid reconfigurations to be made to meet changing production needs.smart factories must be able to adapt fast and smoothly to seasonal changes and market trends.
- **Interoperability**: Objects, machines and people need to be able to communicate through the Internet of Things and the Internet of People.
- **Virtualization**: CPSs must be able to simulate and create a virtual copy of the real world. Virtualization allows a copy of the warehouse to be created digitally by merging sensor data acquired from monitoring physical processes and equipment with virtual warehouse models and simulation models. The virtualized view of operations helps to monitor physical processes and is then visualized through a 3D interface that allows warehouse operators and managers to better manage growing complexity, reduce equipment downtime and optimize processes
- **Decentralization:** The ability of CPSs to independently come up with decisions and carry out their dedicated functions. This gives room for customized products and problem solving, at their level. This also creates a more flexible environment for production. In cases of failure or having conflicting goals, the issue is delegated to a higher level. The concept is characterized by greater customization of products in flexible manufacturing environments, as in industries dealing with mass production.
- **Real-Time Capability**: A smart factory needs to be able to collect real time data, store or analyze it, and make decisions according to new findings. This is not only limited to market research but also to internal processes such as the failure of a machine in production line. Smart objects must be able to identify the defect and re-delegate tasks to other operating machines. This also contributes greatly to the flexibility and the optimization of production.
- **Service-Orientation:** Production must be customer-oriented. People and smart objects/devices must be able to connect efficiently through the Internet of Services to create products based on the customers specifications. This is where the Internet of Services becomes essential.

In the next section, we explore the technologies that are required to accomplish the functional domains of Industry 4.0

B. Technology involved in Industry 4.0

The functionality of the functional domains of Industry 4.0 described in the earlier section, gives us an insight into the technology that get involved in the process, which is described in the following table.

Since most of the technology involved in the above table is data-driven with the increased connectivity from the IoT and Cloud, the security of information becomes paramount. Thus, Besides the above technology listed in the table, Cyber Security is the technology which gets correlated with almost all the funtional domains of Industry 4.0. Reliability and

Functional domains	Technology involved
Designing	Design Technology Autonomous Robotics Internet of Things Internet of People
Modularity	Design Technology Autonomous Robotics Additive Manufacturing
Interoperability	Internet of Things Internet of Service System Integration
Virtualisation	Simulation Internet of Things Data Analytics Aritficial Intelligence
Decentralisation	Data Analytics Artificial intelligence Cloud computing
Realtime-capability	Data Analytics Simulation Cloud computing Artificial Intelligence
Service-orientation	Artificial Intelligence Cloud computing Data Analytics

TABLE I
FUNCTIONAL DOMAINS- INDUSTRY 4.0

sustainability of Industry 4.0 depends much on the cyber security. Thus the technology that get involved in Industry 4.0 are : Design Technology, Autonomous Robots, Artificial Intelligence,Data Analytics,Industrial Internet of Things System Integration, Simulation, Cyber Security.

C. *Framework of curriculum for EE 4.0*

Curriculum is an academic action plan, the base on which the whole of engineering education stands. Our main objective for EE 4.0 is to make the engineers ready for industry 4.0. From now on wards, discipline means the disciplines of engineering such as: electrical engineering, mechanical engineering, computer engineering etc. The so called Engineer 4.0 should have the competency to handle the issues and the challenges that may arise in future. That is, we have to make our graduates ready to solve the problems we do not know are problems yet. So, our curriculum should be dynamic,agile and resilient, to meet any future demands.

As usual, any curriculum should have the components such as Technical component, Soft-skill component, and a Social component, to impart the respective competencies to the graduates. Under the technical component, the basic knowledge and specialised knowledge related to various domains of the discipline of engineering will be imparted. For example, the technical component of the curriculum of Electrical engineering will have specialised knowledge related to various domains of electrical engineering such as Communications and Digital Signal Processing, Computers, control, Electromagnetics, Electronics, Energy & Power, photonics etc. Every discipline of engineering will have various domains under it, like in the case of electrical engineering. Technical component of the curriculum will have the courses related to various knowledge-domains as well as the cross-domain courses. Same is the case with that of the other components of the curriculum. The soft-skill component of the curriculum will have courses related to Communication skills, Organisation skills, Professional ethics, Inter-personal skills, Teamwork skills etc. The social component of the curriculum will focus on the courses related to social ethics, values, project management, social responsibility and accountability. We prepare a Program outcomes which lists out the various skills and competencies that is expected to be possessed after the successful completion of the program. Program outcomes is the skill-set to be possessed by the engineer of that discipline. This program outcomes is prepared based on the expected problems that can be handled by the engineers of the specific discipline. Every course will have a specific outcomes called course level learning outcomes. The educators plan the list of courses that are to go into the curriculum of an engineering discipline, in such a way that the learning outcomes of all the courses gets mapped perfectly into the program outcomes (skill-set) of that specific discipline.

Soft-skill component and the Social-skill components of the curriculum are common to any engineering discipline. For the curriculum of Industry 4.0, soft-skill component and the social components can be same as that of the respective components of any engineering program. For that reason, this paper does not discuss Soft-skill component and the social component of the curriculum. Hence,we focus on the technical component of the curriculum alone. Whenever me mention a curriculum, we mean the technical component of the curriculum.

Thus, under the technical component of the curriculum, we have a list of courses under the various knowledge-domains of a discipline of engineering (like say, computer engineering) whose outcomes gets mapped with the Program outcomes of the engineers of that discipline. Program outcomes is an indicator of the competencies of the graduates, which is knowledge-based. With that competence, students are expected to solve the real-time problems. It is good to note that program outcomes are not prepared in reference to the real-time problems that are solvable by the engineers. Once the program outcomes are achieved, we expect the graduates to solve the real-time problem. It is just an expectation. Further, we cannot prepare the program outcomes by considering all the real-time problem that exists now or that may exist tomorrow. No body knows, what problems will arise in future. In summary, the functional domain of an engineer (of any discipline), cannot be defined properly, where as the knowledge-domains (various domains of knowledge that exist in that discipline) are defined properly. One reason for this is that all the real-time problems require multi-disciplinary competency to solve the problem, beyond the scope of the competency of one engineering discipline. By functional-domain of an engineer we mean the set of well-defined roles engineers are expected to play. Engineers are expected to solve any type of realistic problems that may arise, with their life-long learning ability. In one sense, the program outcomes act as an interface between the knowledge-domains of the discipline and the functional-domain of the discipline.

In the case of Engineers of Industry 4.0, the functional domain is clearly defined as mentioned in Table I. Roles of an engineer under Industry 4.0 are: designing the cyber physical systems, interoperating the CPS, Modularizing the CPS, decentralising the CPS, simulating and virtualising the CPS, analyse the data generated by the CPS, Optimizing the real-time capability of CPS and producing the CPS based on the demand. This is the exhaustive list. As mentioned in section II, the knowledge-domain under each functional domain are the technologies that get involved in it. That is, knowledge-domains under Virtualisation are : Simulation, Internet of Things, Data analytics and Artificial intelligence. One could observe that the knowledge-domains of Engineers of Industry 4.0 does not get confined to one particular discipline of engineering. All the disciplines such as mechanical engineering, electrical engineering, electronics engineering , computer engineering, get involved in all the functional domains. The Engineers of 4.0 are expected to gain the skill and the knowledge related to all the disciplines of engineering. There is nothing like referencing a person with 'an electrical engineer of Industry 4.0'. The functional domains of Industry 4.0 will serve the purpose of verticals. After the bachelor level, an Engineer 4.0 can specialize in any of the verticals at the master's level. An Engineer 4.0 specialized in interoperability can be called as Interoperable Engineer of Industry 4.0 As mentioned earlier, the cyber security is ubiquitous in all the knowledge-domains.

In summary, the proposed technical component of the curriculum for Industry 4.0,, called as Curriculum 4.0, as in Table II will have the knowledge-domains : Designing, Modularity, Interoperability, Virtualization, Decentralization, Real-time capability, Service-orientation.

Courses in each of the domain should be properly designed in such a way that all the topics listed against that domain, gets included in the course in such a way to impart the required knowledge of that domain. It is not advised to list courses on each topic and leave it to the graduates to gain knowledge of that domain. We have to avoid the redundant duplication in the process. This proposal is just a framework for the curriculum. A lot more fine-tuning has to be done.

In the usual curriculum design, we start from the knowledge-domain and try to reach out to the functionality. Only for that reason, we are expected to map the course-level learning outcomes with the programme outcomes, so that one can be sure of the competency of the graduates in serving the purpose. As mentioned earlier, programming outcomes acts as an interface between the knowledge-domain and the functional domains. But, in the design of the curriculum 4.0, we started the process from the other direction. We started from the functional-domain and made that as the knowledge-domain for listing the required courses. Functional domain has replaced the knowledge domain. The, there is no need for an interface called programme outcomes. In that context, the course-level outcomes of all the courses will automatically form the programme outcomes.

Domains	Courses involving
Designing	Design Technology Autonomous Robotics Internet of Things Internet of People Cyber security
Modularity	Design Technology Autonomous Robotics Additive Manufacturing Cyber security
Interoperability	Internet of Things Internet of Service System Integration Cyber security
Virtualisation	Simulation Internet of Things Data Analytics Aritficial Intelligence Cyber security
Decentralisation	Data Analytics Artificial intelligence Cloud computing Cyber security
Realtime-capability	Data Analytics Simulation Cloud computing Artificial Intelligence Cyber security
Service-orientation	Artificial Intelligence Cloud computing Data Analytics Cyber security

TABLE II
TECHNICAL COMPONENT OF CURRICULUM 4.0

III. CONCLUSION

Thus, the proposal of the framework of the curriculum for Industry 4.0 provides a scope for the generation of discipline-independent Engineer 4.0 to meet the future demands. All the major engineering disciplines gets amalgamated in the knowledge-domains of Industry 4.0. This is something like the amalgamation of the knowledge of various disciplines like civil engineering, mechanical engineering, electrical engineering, electronics engineering, computer science engineering that goes in to the designing and the construction of a smart house with all the modern amenities. All the present teachers of engineering education are the products of the discipline-based engineering education. Ability of those teachers in imparting the comprehensive competency (involving all the disciplines) to the graduates such that engineers 4.0 are competent enough to perform all the functional roles expected of an engineers 4.0, is going to be a major challenge in the implementation of the curriculum 4.0. Further, the designing and the preparation of the contents of the sequence of courses under each knowledge-domain such that contents of the course converge to the functional requirements of the Industry 4.0. Further studies can get initiated to gauge the impact of the notion of discipline-independent engineering in all the stages of engineering education.

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