Where to gain future competencies for Industrial Product-Service Systems (IPS^2)?

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INTRODUCTION

The job demands of engineers have increased rapidly over the last decades. The complex competitive situation in a globalised world [1], the technology advances, the pervasive use of information technology, the modification of value-added chains, the need for intercultural teamwork [2,3] are some of the major factors, that have a great impact on job market requirements for engineers. Industry stakeholders have acclaimed early, that the engineering education does not prepare the engineering graduates for the social, economic and technological challenges and that there is a strong need for curricula reform [4,5]. It was stated, that universities and industry have developed as two separate entities with different dynamics [6,7], causing a competency gap between the desired graduate competence profiles and the preparation through the educational institutions [8].

Efforts to overcome this gap led since the early 1990s to a significant paradigm shift in engineering education [8]. The traditional discourse focused on the input side of teaching, on what resources are available for the student, shifted to a system based on educational outcomes [9]. One of the key topics concerned the quality control of the independent national agencies to accredit new curricula, giving the outcome based education a structural capacity where the relevant stakeholders of industry, university and professional organizations decide together on the outcome definitions and the criteria’s of quality assurance of study programs. The system of quality assurance ensured the industry the possibility to bring their understanding of the relevant competencies into account. Due to the system requirements, the accreditation system is focusing on the professional competencies according to the different subjects of study, e.g. mechanical engineering, electrical engineering etc., not on the competence demands of the specific job areas the graduates are going to work in. Nevertheless engineering education assumes the responsibility for preparing students for professional competence [8]. One specific and prospective job area are Industrial Product-Service Systems (IPS^2). Within IPS^2 not merely product or service function as an offer for the customer, but an entire problem solution for business-to-business markets, tailor-made to individual customers' needs [10]. IPS^2 are characterized through a high demand for coordination, communication and knowledge integration among the original manufacturer, its suppliers and customers [11].

Therefore, this article aims to provide insight into the sources of crucial engineering competencies by presenting data from the HIS graduate panel, a representative large scale survey with longitudinal data conducted in Germany. On the basis of this data set we specify further the competencies that enable the engineers to perform in in IPS^2 work environments and we take a closer look at the various impacts on the required competence profile of engineers – is it mainly generated through the study program, training on or off the job, or is professional experience the key factor? The data evaluation is based on multiple regression analysis. The findings allow a critical discussion whether we need a further development of university curricula or a new perspective on the post-graduate training period.

The article unfolds as follows: First, we will have a closer look at the paradigm shift in engineering education as an antecedent for this development. We concentrate on the shifts concerning the learning outcomes and the learning methods - aiming to identify the major sources of competence and the competence requirements of engineers. We contribute to the further development of engineering curricula and competence development of engineers by highlighting the importance of specific competencies and facilitating aspects concerning the learning methods.

1 PARADIGM SHIFT IN ENGINEERING EDUCATION

1.1 Outcome based education

The paradigm shift in engineering education consists of numerous interdependent aspects. The shift of the input orientation towards "a system based on educational outcomes" [8] functions as a key driver. The outcome based education (OBE) is on the one hand an assessment approach, on the other hand a whole process, that involves the restructuring of curriculum, assessment and reporting practices in education to reflect the achievement of high order learning and mastery in contrast to the old approach focusing on the accumulation of course credits [12]. The focus is shifting from what graduates learn in higher education to what the graduates are able to do within their working requirements [12,13]. The concept of "competencies" functions as the nuclear concept behind this approach [14]. Competencies define the ability to develop problem solving through self-organized actions as well as the ability to create new aspects in ambiguous and complex situations and open assignments of tasks in process orientated work system [15]. The concept of competence takes into account that current state of the art knowledge and technologies are superseded in decreasing time segments. The specific expert knowledge for most occupations only lasts for approximately five years [16]. As a consequence, the ability to learn and to adapt to new challenges is getting more important than the once acquired qualifications. Within the paradigm shift in engineering education especially two questions had to be answered:

- What kind of competencies do engineers need to cope with the demands of their job environment? (Competence dimensions)
- How can the competencies be obtained? (Learning theories & learning methods)

1.2 Competency Requirements of Engineers

The traditional model of engineering is mono-disciplinary and assumes that graduates will work as specialists [17]. In the 1980 and 1990s the tension between the two key objectives of engineering education escalated: The need to educate students as specialists for technologies with increasing levels of knowledge and teaching them to become generalists in a range of “personal, interpersonal, and product, process, and system building skills” [18]. Industry representatives have stated early, that there is a gap between the competency requirements of engineers in a globalized world and the actual competencies of engineering graduates [1]. To overcome this gap the new bachelor and master programs include transferable competencies that are required for practical engineering activities and beyond. Nevertheless it is still an on going discussion how these guidelines can be transferred into curricula and what competencies exactly should be acquired [19]. One approach to specify the competencies is to take a closer look at a prospective future work environment for engineers - Industrial Product-Service Systems (IPS^2). Industrial Product-Service Systems (IPS^2) have become a major research focus during the last years [20]. The growing global competition, especially considering the emerging BRIC countries [21] puts the industry sector under pressure as the quality and technology gap of former years lost its function as apparent competitive advantage to the more favourable prized products from the BRIC countries. One approach to sustain competitiveness is offered by the introduction of IPS^2. Companies can use the possibility to integrate their products and services to offer a value added solution and to build up a long term business relationship with their customers [22]. IPS2 function as prime example for the transition to a third industrial revolution. From the first revolution with the mechanization of the textile industry to the second revolution with Henry Ford’s assembly line the third revolution now takes manufacturing to a digital age with more flexibility, less manpower and new collaborative manufacturing [23]. The demands for IPS2 contexts include heterogeneous fields of expertise that need to be integrated and high coordination requirements due to the customer driven flexibility of the business model [22]. To cope with these demands specific competencies of individuals and teams are needed [24,25]. Following the competence dimensions of Erpenbeck and Rosenstiel [26] it has already been shown, that engineers working in IPS^2 environments perceive personal competencies, activity- and implementation-oriented competencies, professional skills and methodical competencies as well as social and communicative competencies as more important to cope with their high demanding work environment than their colleagues working in conventional environments in the engineering sector [25]. After we have shown the shift in the competence requirements of engineers, we will now have a closer look how engineering education developed within the last century concerning the attitude of how competencies can be acquired.

1.3 Learning Theories and Learning Methods

The leading discourse in learning theory before the cognitive turn was the behaviourism with the traditional research paradigm the “Skinner-Box”. According to his model, changes of behaviour are based on stimuli that occur in the environment, leaving the mental processes in a black box. Applying his concept to human behaviour, he invented the teaching machine that provided immediate and regular reinforcement on the students’ behaviour [27]. His model stressed the role of the teacher as the main factor for the student’s learning. Adaptations of the behaviouristic view of learning are still frequently applied in engineering education [28]. The cultural-historical school of learning [29] stressed the role of social practices for learning, the application on learning methods in engineering education can be seen in laboratory and project work [28]. The role of the teacher shifted from the traditional role to a more supervising role. The socio-cultural learning theory focused on the interaction between the individual and society, stressing the role of mediating practical and intellectual tools in the frame of institutionalized practices [30]. Applying this concept to engineering education, not only the opportunity for the students to interact is important, but also the provision of the necessary tools to enable the students’ self-reliance. In contrast to the radical behaviourism, cognitivism took a closer look at the innate aspects of learning [31]. The mental processes and the cognitive abilities of individuals, which were considered to be a “black box” until then, became the main focus of this research stream. Therefore the role of the student shifted from a rather passive to an active role: Understanding is not developed through passive repetition but through actively involving the student in the learning process including the reflection of the process itself. Engineering students therefore should be empowered to actively explore things ore situations [28]. Whereas behaviourism with the focus on the teacher stands for the traditional important role of lectures in engineering education, cognitive approaches stress the benefits for the learning process when students are actively involved, e.g. active learning, problem oriented and problem based learning.

The social-cognitive theory is a rather holistic approach, taking personal, behavioural and environmental determinants and their interactions into account. [32]. Learning in this sense is not merely the acquisition of knowledge in a cognitively reactive sense but involves furthermore the development of self-beliefs and self-regulatory capabilities of students. According to social-cognitive theory sources of self-efficacy are enactive mastery experience, vicarious experience, cognitive stimulation and verbal instruction. Enactive mastery experience is the most influential source of efficacy information because they provide the most authentic evidence of whether one can act successfully [32]. Vicarious experience mediated through modelled attainment is another important source of self-efficacy. The possibility of social comparison is important to raise efficacy beliefs. Verbal persuasion can help to raise efficacy beliefs if significant others express faith in one’s capabilities. Physiological and affective states are the fourth of the major parameters introduced by Bandura. The social-cognitive theory furthermore points out, that students are more motivated when they believe that the outcome of learning is under their control [32], research in problem-based learning [33] and especially self-directed learning [34] evidenced Banduras approach and its benefits for curricula development.

In order to narrow these preliminary trends in changing engineering work environments and engineering education down and to have a closer look at their factual consequences for researchers and practitioners in the field of curricula and competence development of engineers, we will now present our explorative research design focusing on the role of engineers and the origins of the crucial competencies in IPS² work environments. Thereby, we will consider IPS² as a contextual background since these innovative value creation systems present a prime example for future engineering work environments.

2 FINDINGS

2.1 The Sample

The HIS graduate panel is a representative large scale survey with longitudinal data conducted in Germany with the year of 1989 as a starting point. It is representative for the population of German graduates in engineering studies. The survey is conducted in three waves. We used the data of the third wave, asking participants who graduated from their universities in 2001. The following items have been used to identify the participants of the survey working in an environment which shows PSS- or IPS²-relevant characteristics:

- Within my job, I have to deal with new challenges which often cannot be handled by a linear solution.
- Only the combination of specific knowledge from different experts leads to success during my work.
- The colleagues with whom I work have very different professional backgrounds.
- The output of my work is required by others before they are able to fulfil their tasks.

2005 engineers took part in the panel, 791 answered the IPS^2 specific filter questions. The mean year of birth is 1974 and the standard deviation is about 2.5 years; subsequently, the mean age is about 38 years.

Within our sample we identified 24 engineers that work in environments that can be fully characterised by all of the above mentioned IPS^2 features through generating an extreme group.

2.2 Identifying relevant competencies to cope with IPS^2 environments

To answer the research question, where future competencies for Industrial Product-Service Systems (IPS^2) can be gained, we started our analysis by detecting the crucial competencies that engineers especially need to cope with this demanding work environment. Therefor we distinguished the required competencies of engineers working in environments with IPS^2 characteristics with all engineers using a paired t-test in which the means of both groups are contrasted. Engineers in IPS² work environments perceive larger requirements than engineers in general, especially with regard to the highlighted competencies.

Table 1. Comparison of Means - competencies and abilities required in work environment with IPS^2 characteristics

Perceived required Competencies and Abilities	**IPS² (n=24)**	**Other engineers (n=767)**	**T**
Ability to cope with changing circumstances	4,58	4,04	2,76**
Ability to assume responsibility	4,38	4,17	1,12
Ability to cooperate	4,29	3,91	2,17*
Negotiation skills	4,63	3,59	8,20***
Leadership skills	3,88	3,27	2,42**
Communication skills	4,88	4,40	6,36***
Written expression ability	4,21	3,89	1,61

Oral expression ability	4,42	4,12	1,83
Conflict management	4,33	3,58	5,55***
Specific specialist knowledge	4,25	4,16	0,50
Broad basic knowledge	4,33	4,06	1,52
Knowledge about scientific methods	2,63	2,75	0,52
Interdisciplinary thinking	4,38	3,90	3,49***
Foreign languages	3,00	2,95	0,16
Computer literacy	4,29	4,17	0,68
Business skills	3,13	2,58	2,49**
Organizational capability	4,71	4,33	3,87***
Problem solving skills	4,75	4,23	5,56***
Ability to work self-dependent	4,92	4,57	5,66***
Time Management	4,50	4,18	1,84
Ability to use existing knowledge to solve new problems	4,67	4,16	4,25***
Ability to detect and close knowledge gaps	4,04	3,78	1,43
Analytical skills	4,33	3,80	2,72**

N=791; 5-point-Likert-scale (1=not important at all – 5=very important

As a next step we took a closer look at the gap between required and existing competencies. There for we selected the competencies with significant impact to derive the development potential for engineers working in IPS² environments. This is depicted in the diagram below.

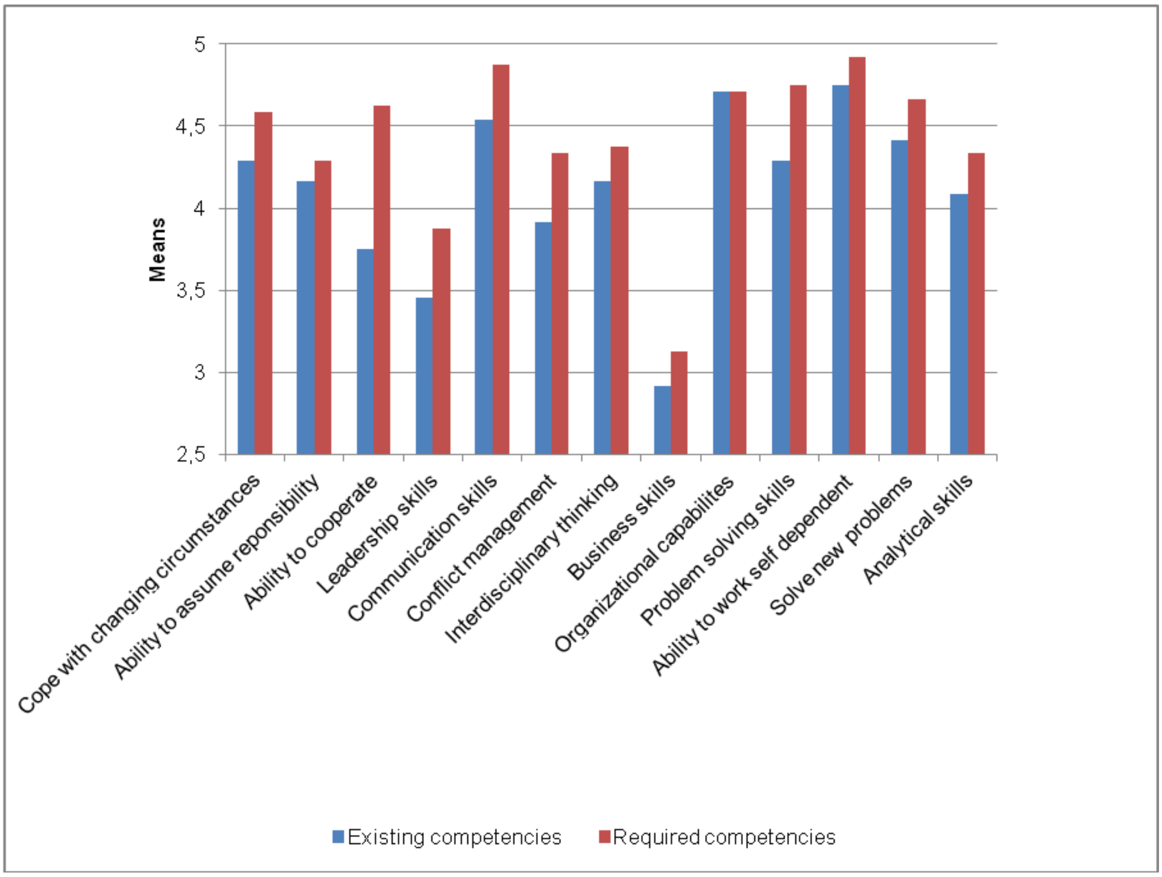

Fig. 1. The competence gap of engineers working in IPS² environment (n=24) - means of existing and required competencies

Since negotiation, leadership, communication and problem solving skills as well as conflict management abilities showed the highest development potential, we took a closer look at these abilities in order to get insights about where they are gained. We used five multiple regression analyses in which the five critical abilities mentioned above represented the respective dependent variable. The age and job tenure as well as different training types constituted the independent variables. The results of these five analyses are shown in the table below.

Table 3. Multiple regression analysis of competencies and learning environments

	Negotiation skills	Leadership skills	Conflict management	Communication skills	Problem solving skills
Age	.030	.004	.064	.029	.001
Work tenure	.070	.089*	.019	.015	.136***
Further education	.046	.015	.136**	.063	.036
Lectures	.066	.031	-.042	.007	.008
Fair trades	.028	.055	.052	.067	.076
Professional literature	.006	.053	.036	-.040	-.023
Self-learning	.029	.097*	.104*	.047	.071
Learning from colleagues	-.041	.012	.005	.058	.000
In-house trainings	-.015	-.018	-.018	-.024	.012
Quality and workshop circles/ Participation groups	.127***	.135**	.032	.032	.030
Supervision/Coaching	.029	.099*	.112**	.121**	.047
Internet learning opportunities	-.143***	-.027	-.072	-.059	.096*
E-Learning	.007	-.036	.052	-.028	-.031
R^2	*.05****	*.09****	*.07****	*.04***	*.07****

*p<.05, **p<.01, ***p<y.001; N=719-725 due to pair wise deletion of missing variables, standardized regression coefficients, work tenure is operationalized in month with a possible max. of 120

Overall the effects are not very strong. It can be stated, that work tenure contributes to problem solving skills (β=.136, t=3.60, p=.000), whereas negotiation skills can be supported by quality circles, workshop circles and participation groups (β=.127, t=2.87, p=.004). Conflict management skills can be supported through further education (β=.136, t=3.13, p=.002) and supervision/coaching (β=.112, t=2.68, p=.008). The findings indicate furthermore that supervision and coaching also have a positive impact on communication skills (β=.121, t=2.86, p=.004). Internet learning opportunities have a negative impact on negotiation skills (β=.007, t=0.17, p=.086).

3 DISCUSSION

As shown in Table 1 engineers in work environments with IPS^2 characteristics are confronted with a higher demand of required competencies than engineers in general, especially concerning negotiation, communication and problem solving skills as well as the ability to work self-dependent and conflict management skills. The findings support previous research [24, 25]. In the second step we selected the competencies with significant findings to detect the gap between the required and existing competencies of engineers working in IPS^2 environments. The presumption was that the impact concerning the development potential is especially high within the competencies with the greatest gaps. There was no case, in which the existing competencies outbalanced the required competencies. Only within organizational capabilities the existing competencies met the requirements. Negotiation, leadership, communication and problem solving skills as well as conflict management abilities showed the highest development potential. Therefor universities as well as employers should focus on the development of these competencies. In the next step we took a closer look to detect how and where these competencies can be gained. If work tenure has an impact on a competency it can be taken as an indication, that this competence should be further developed especially within engineering curricula. In this study this is the case for problem solving skills. This stresses the importance of model learning in Bandura's sense for future IPS^2 engineers. One approach for curricula development would be to include problem based learning. In quality and workshop circles as well as participation groups especially negotiation skills are gained. Within IPS^2 work environments engineers are situated in a network composed of the provider, the buyer and suppliers. Different goal settings concerning the respective perspective are inherent. The importance of quality and workshop circles for the development of negotiation skills supports the role of team learning in the sense of vicarious experiences and the necessary openness of organisations for new solutions that are introduced in a bottom up direction. Further education has a positive impact on conflict management, as it is differentiated from in-house training; it stresses the aspect of integrating perspectives of engineers representing various organisations in a group setting. Supervision and coaching have a positive effect on conflict and communication skills. Persuasive techniques are widely used by coaches and supervisors to increase the self-perceptions of efficacy. This aspect supports approaches for development activities on the individual level. We could detect one negative effect – internet learning opportunities have a negative effect on negotiation skills. As the role of internet learning is of growing importance for universities (e.g. MOOCs) and companies, developers of programmes should integrate more interactive parts with other co-users. The presented learning environments and methods that are characterized with less social interaction – internet learning, self-learning, professional literature, E-learning and lectures – have no or even a negative impact on the competencies. Therefor social interaction should be a key aspect for developing IPS^2 specific training methods. Generally speaking the paradigm shift in engineering education concerning the role of the learner from a rather passive student to an active and involved future engineer appears as at least on important aspect of an appropriate answer to the changing requirements of engineers.

Although certain aspects concerning the different learning environments could be derived, the rather weak effects indicate, that the analysed training methods are not the key enablers for engineers to develop the required competencies. The limitations are caused primarily on the basis of the questionnaire method. Further research including other empiric methods should be carried out to find the best strategies to develop competent future engineers for IPS^2 work environments.

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