21ST INTERNATIONAL CONFERENCE ON ENGINEERING DESIGN, ICED17
21-25 AUGUST 2017, THE UNIVERSITY OF BRITISH COLUMBIA, VANCOUVER, CANADA

COMPETENCES FOR THE DEVELOPMENT OF SMART PRODUCTS

Herzog, Michael; Bender, Beate
Ruhr University Bochum, Germany

Abstract

Within the concept of Industry 4.0 the expansion of mechatronic products towards smart products is key. Whereas the discussion about smart products in the context of production is more prominent, the shift towards the paradigm of smart products also suggests that the current way of product development needs to be adapted fundamentally. It becomes obvious that besides technological topics like big-data or IT-infrastructure, the human factor is of major importance for a successful realization of industry 4.0. Especially new concepts for training and further education for product development are needed to cope with the emerging challenges. In order to design new educational concepts, instructional goals are key. Nowadays these goals are described in a competence oriented way. Until now, there are now competence models available that consider both the specificity of product development as well as the context of Smart Products. Hence this paper aims at deriving this competence model in a conceptual way. Therefore, a multistaged approach is conducted that synthesizes competence models for product development and engineering for industry 4.0 as well as design methodologies in the field.

Keywords: Design education, Product-Service Systems (PSS), Training, Business models and considerations

Contact:
Michael Herzog
Ruhr University Bochum
Chair of Engineering Design
Germany
herzog@lpe.rub.de

Please cite this paper as:
Surnames, Initials: *Title of paper*. In: Proceedings of the 21st International Conference on Engineering Design (ICED17), Vol. 9: Design Education, Vancouver, Canada, 21.-25.08.2017.

1 INTRODUCTION

The significant role of product development for the economic success of an enterprise is undisputed since developing new products contributes to both innovation and competitiveness. At the same time product development underlies consistent changes due to new market and customer related requirements as well as the technological progress. However fundamental changes occur from time to time like the fourth industrial revolution that is much discussed in politics, industry and research. Within the concept of Industry 4.0 the expansion of mechatronic products towards smart products is key. Whereas the discussion about smart products in the context of production is more prominent, the shift towards the paradigm of smart products also suggests that the current way of product development needs to be adapted fundamentally. As shown within representative studies, there is a consensus among industry experts on changing working processes and contents; new development methods, models and tools (Abramovici and Herzog, 2016; Anderl et al., 2012). Furthermore, many authors claim that these requirements will even lead to new job roles, comparable to the developments in the field of mechatronics in the 1990´s (Müller and Stark, 2014).

It becomes obvious that besides technological topics like big-data or IT-infrastructure, the human factor is of major importance for a successful realization of industry 4.0. Especially new concepts for training and further education for product development are needed to cope with the emerging challenges (Zink and Eigner, 2013; Anderl et al., 2012). Although this issue is repeatedly motivated and highly recommended by various authors and committees, the scientific discourse on the design of training concepts for the development of smart products lacks content until now. The systematic planning of training and teaching concepts is guided by instructional design theories (Edmonds et al., 1994). In accordance with these theories, instructional goals play a central role. Following a paradigm shift (not only) in engineering education, instructional goals are described in an output and competence oriented way nowadays. Thereby the focus is shifting from what graduates learn in higher education towards what the graduates are able to do within their work requirements. In order to gather and systemize the required competences for a specific working context, competences are brought together within competence models. Although there are numerous competence models for product development in literature, these do not consider the specific characteristics of the development of smart products.

Hence this paper aims at proposing a specific competence model for the development of smart products. Thereby the competence requirements must be derived in a conceptual way, which is valid due to the high topicality and the present lack of empirically oriented research (Voigt et al., 2015). The paper is structured into 4 sections, following the Design Research Methodology (Blessing and Chakrabarti, 2009). Within Section 2 (research clarification) we present the foundations to clarify our understanding of smart products as well as competences and competence models. Based on this, Section 3 (descriptive study I) presents the state of the art in design methodologies in the broader context of smart products as well as competence models in the field of product development and industry 4.0, which is necessary to finally deduce the preliminary competence model for the development of smart products (Prescriptive study). The paper ends with a conclusion and an outlook.

2 RESEARCH CLARIFICATION

2.1 Smart products

In the early 1990´s, research about smart products was marked by various disciplines like artificial intelligence, cognition psychology and ubiquitous computing and focused the ergonomic design of machine-user-interfaces (Rijsdijk and Hultink, 2007). Within his visionary article, Mark Weiser described smart products as "[…] richly and invisibly interwoven with sensors, actuators, displays and computational elements, seamlessly embedded in everyday objects of our lives, connected through a continuous network." Within the last years, the term "smart product" was kind of reinvented due to the current innovations in all fields of Information and Communication Technologies and the discussion about industry 4.0. Thereby the definition was broadened and numerous terms like intelligent products or cyber-physical systems are often used synonymously. The international academy for production engineering (CIRP) follows a hierarchical approach by defining smart products as "[…] cyber-physical products/systems (CPS) which additionally use internet-based services in order to perform a required functionality. CPS are defined as „intelligent“mechatronic products/systems capable of communicating and interacting with other CPS by using different communication channels, i.e. the internet or wireless lan." (Abramovici, 2014). It becomes obvious that this definition shows a distinction between smart products and smart services. However, the authors suggest a more economically definition approach, according to which, a product is a marketable object for the solution of a customer problem and can contain both material (technical systems) and immaterial (e.g. services or software) elements. Consequently, the services have to be considered as an integral element of smart products so they should be regarded as Product-Service Systems[1] (Abramovici and Herzog, 2016). The degree of service integration can reach from supporting the product (e.g. spare part management or maintenance services) to service-oriented business models that support the customer (Baines et al., 2016). Instead of selling products in a traditional way by transferring its ownership, these business models link the revenue streams directly to the usage or the performance of a system. Thus, they enable a transfer of risks, customers normally must cope with on their own. For instance, a provider guaranteeing (and paid for) the availability of a manufacturing system transfers the financial risks of potential system downtimes (Meier et al., 2010). Summarizing, the characteristics listed in table 1 illustrate that it is difficult to strictly separate the certain types of systems mentioned above.

Table 1. Characteristics of Smart Products

Intelligent mechatronic systems (Dumitrescu, 2010)	
Adaptability	Systems can develop further (within predefined degree) their selves during runtime
Robustness	Systems can handle unexpected situations. Uncertainties and missing information can be compensated to a specific degree
Effectiveness	Systems realize proactive behavior by anticipating future conditions. Hazards and risks can be avoided, goals can be reached more quickly and with a higher quality
User-orientation	Recognize specific user behavior and optimize their behavior based on historical data
Cyber-Physical Systems (Geisberger and Broy, 2015)	
Physical Awareness	Sensor fusion, pattern recognition, situation recognition
Autonomous planned acting	Multi-criteria situation assessment, artificial intelligence approaches
Cooperation and negotiation	Multi-agent systems
Human machine interface	Intention and plan recognition, user and human modelling
Learning	Machine learning and data mining
Evolution	Multi-agent systems, self-organizing communication networks
Product-Service Systems (Müller, 2013)	
Theory characteristics	Product and service integration
	Application of (long term) business and operating models
	Lifecycle orientation and sustainability
	Customer orientation and customer value
Practice characteristics	Individual character, Complex systems and use conditions
	Changing requirements during operation and needs for adaption
	Distributed use (pooling, sharing)
	Systems with extreme requirements on availability
	Long term business relationships but high risks and costs

Furthermore, especially when comparing the characteristics of Product-Service Systems with the beneficial properties of Intelligent Mechatronic Systems and Cyber-Physical Systems it becomes obvious that there is potential for synergetic interaction (Lindemann, 2015; Geisberger and Broy,2015).

2.2 Competences and competence models

The discussion about competences is characterized by a high degree of heterogeneity which is already reflected by the ambiguous meanings when looking it up in a dictionary. Competence means is described by expertise, skills, capabilities as well as responsibility. Proposed synonyms are talent, ability,

[1] This assumption is not mandatory the other way around, because not every Product-Service System contains CPS or intelligent mechatronic systems.

qualification or gift. This high variety of the concept of competences can be explained by the numerous disciplines it is scientifically acknowledged by, like human resource and work process management, strategic management, pedagogic or instructional psychology. Regarding the pedagogical and instruction psychological scope addressed in this paper, Klauer and Leutner state that competence means, that a person can master (know how) a specific situation (know what) (Klauer and Leutner, 2012). This refers to the famous Bloom´s taxonomy for instructional goals, which was developed further by Anderson und Krathwohl later. Thus competences (as instructional goals) are formulated by the content (knowledge dimension) and a description, what to do with this content (cognitive process dimension) (Krathwohl, 2002). Klieme and Hartig declare, that the ability to use cognitive potentials in always new situations is a constitutive attribute of competence. Therefore, competences aim at outlasting effects (Hartig and Klieme, 2006). A more differentiated approach is proposed by Weinert, who distinguishes different types of competences. Thus, a person needs as well generic competences for different kinds of tasks, context-specific competences for specific categories of situations and a motivational orientation to finally handle the requirements in a specific field of action, for example a profession like product development. In addition, meta-competences enable on the one hand the determination of the need and on the other hand the acquisition of new competences itself. Finally, key competences like mother-tongue or mathematical expertise are relevant for a broad range of situations (Weinert, 1999). Bergenhenegouwen et al. propose four subdimensions of vocational competence: knowledge and skills (1), social, organizational and communicative skills (2), values, standards, moral criteria (3), self-image, motives, effort and enthusiasm (4). Within this competence model, the necessary knowledge, skills, abilities and personal characteristics are systematized in a hierarchical way (Bergenhenegouwen et al., 1996). Another widespread competence model is proposed by Erpenbeck and Rosenstiel. It contains the competence dimensions of professional and methodical competence, social-communicative competence, personal competence and activity competence with each diverse subdimensions (Erpenbeck and Rosenstiel, 2007). Although competence models like the one proposed by Erpenbeck and Rosenstiel, the European Qualification Framework (EQF) or the German catalogue of competences of the national agency for deployment, enable a definition of competences for a broad range of professions, they are not appropriate to describe specific competences in a relevant field, due to their generality. Previously, competence models in the context of smart products and industry 4.0 are intended to provide dimensions of competences for the domain of engineering in general. Mostly related to production work more closely, these models do not consider the specific characteristics of the working system of product development. In contrast, there are competence models proposed in literature that even though address product development, but are not concretized to the characteristics of smart products. As shown in figure 1, there is no competence model specified for the development of smart products so far (dark grey field). In order to derive domain-specific instances, more generic competence models can be used as a framework (Drechsler, 2016). Based on the generic dimensions, the main abilities and requirements of the considered vocational environment must be deducted. Thereby the elicitation of these requirements can be approached in different ways, like literature studies, interviews with experts, questionnaire survey.

3 COMPETENCES FOR THE DEVELOPMENT OF SMART PRODUCTS

In order to define the competence model for the development of smart products, the subsequent literature-based descriptive study aims at answering the following research questions:

- RQ1: Which competence models are suitable to serve as a framework for the specific competence model for the development of smart products? (Chapter 3.1).
- RQ2: Which specific competences can be derived from the characteristics of the working system of the development of smart products? (Chapter 3.2).

3.1 Development of a suitable competence framework

In order to contribute to the first research question (RQ1) a literature study is conducted that approaches the competence framework in a bilateral way as shown in Figure 1. In the first step, existing competence models in the domain of product development are analysed regarding their specificity and level of detail (Chapter 3.1.1). The resulting domain-specific but context-independent competence framework is juxtaposed with the new requirements and competences anticipated with engineering in the context of industry 4.0 in general, to finally highlight the most important sub-dimensions of competences needed for the development of smart products (Chapter 3.1.2).

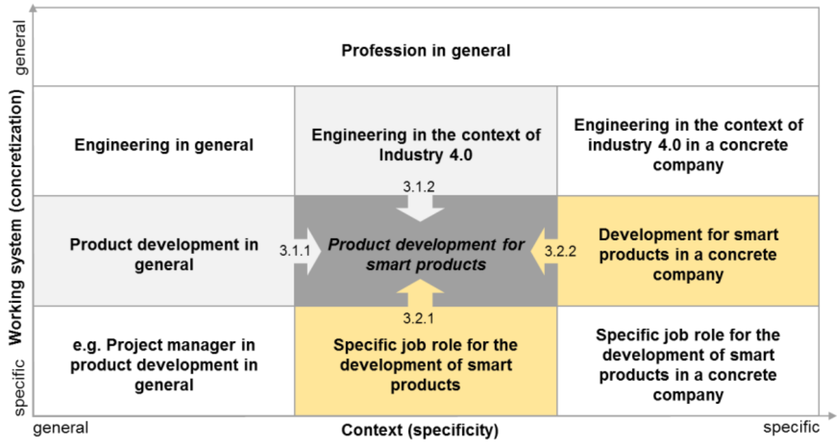

Figure 1. Typology of competence models

3.1.1 Competences for the domain of product development

There are various competence models existing in the domain of product development, separately focusing specific aspect implicitly due to several school of thoughts or historical dependencies. To get a preferably holistic view, the following analysis is guided by the CDIO[2] syllabus version 2.0 (Crawley et al., 2011). This taxonomy for learning outcomes was originally conceived at the Massachusetts Institute of Technology (MIT) in the late 1990´s. The goal was to create a taxonomy that is rationalized against the norms of contemporary engineering practice, comprehensive of all known other sources and peer reviewed by experts in the field. Nowadays more than 100 universities around the world are using this competence model to derive their engineering programs and curricula. As shown in various studies, the CDIO syllabus is the most complete and consistent competence model in the field of engineering. Especially the high degree of detail regarding the context of engineering work (conceiving, designing, implementing, operating) is seen as beneficial to overcome the lack of convergence between engineering education and industrial practice (Crawley et al., 2011). In 2011 the syllabus was revised within a review process (including focus group discussion, document research, surveys, workshops and peer reviews) to integrate missing skills and to make it more consistent with other standards. Like sown in Figure 2 (on the left), the resulting CDIO syllabus version 2.0 classifies learning outcomes into four high-level categories that are further specified within three more levels: Disciplinary knowledge and reasoning (1), personal and professional attributes (2), interpersonal skills (3) and skills that are specific to the engineering profession, like conceiving, designing, implementing, operating (4). Furthermore, there is an optional extension explicitly addressing leadership and entrepreneurship, which are more and more relevant in engineering work systems. In order to find a suitable competence framework, the CDIO syllabus version 2.0 is compared to domain-specific competence models. The goal is to determine a more domain-specific view and find out about the most important competences for product development. Therefore, a literature research has been conducted. Journal articles, papers and books were obtained from Springer Link, Web of Knowledge, Google Scholar and Google. The investigation concentrated on publications that included at least one of the following key words "competence models", "attributes", "skills", "qualification" in combination (conjunction) with the key words "product development", "engineering design" and "product innovation" in English and in German. As shown in Figure 2, the identified competence models for product development are analysed due to their correlation with the CDIO syllabus v2.0. Although the CDIO syllabus implicitly identifies a generic set of skills needed by all engineers, there are more specific sets for different career tracks (Crawley et al., 2011). Due to the focus of this analysis, the specific skills of system designers (4.3) and device designers (4.4) are of special interest. Therefore, only these competences are specified towards level three to receive a

[2] CDIO is an acronym and stands for Conceiving, Designing, Implementing and Operating, which are the main activities of hardware, software and process engineering.

more differentiated view on the one hand and to reduce the complexity of the analysis on the other hand. Within the analysis, we distinguish between two categories of correlation. A weak correlation (bright grey) shows that a single CDIO competence is confirmed within the specific competence model. In contrast, a strong correlation (dark grey) goes beyond that and specifies a CDIO competence in more detail, e.g. enumerate methods used to consider customer needs within the development process.

CDIO Syllabus v2.0 (Crawley et al. 2011)				Kovacevic, A. (2008)	Binz (2014)	Albers et al. (2012)	Kunrath et al. (2016)	Riel, A. (2010)	Beitz and Helbig (1997)	Mountain, J. (2013)	Conley, C. (2004)	Goff and Terpenny (2012)	Schreiner, M. (2005)	Blum, M. (2004)
Level 1		**Level 2**	**Level 3**											
1. Disciplinary knowledge and reasoning	1.1	Knowledge of Mathematics and Science												
	1.2	Core Engineering Fundamental knowledge												
	1.3	Advanced Engineering knowledge, methods and tools												
2. Personal and professional skills and attributes	2.1	Analytical reasoning and problem solving												
	2.2	Experimentation, investigation and knowledge discovery												
	2.3	System Thinking												
	2.4	Attitudes, thoughts and learning												
	2.5	Ethics, equity and other responsibilities												
3. Interpersonal skills: teamwork and communication	3.1	Teamwork												
	3.2	Communications												
	3.3	Communication in foreign languages												
4. Conceiving, Designing, implementing, and operating systems in the enterprise, societal and environmental context - the innovation process	4.1	External, societal, environmental context												
	4.2	Enterprise and business context												
	4.3	Conceiving, systems engineering and management	Understanding needs and setting goals											
			Defining function, concept and architecture											
			System Engineering, Modelling and Interfaces											
			Development Project Management											
	4.4	Designing	Design process											
			The Design process phasing and approaches											
			Utilization of knowledge in design											
			Disciplinary design (e.g. appr. Techniques, tools and processes)											
			Multidisciplinary Design (e.g. interactions between disciplines)											
			Design for sustainability, safety, aestetics, operability, other objectives											
	4.5	Implementing												
	4.6	Operating												
Optinal extension	4.7	Leading engineering endeavours												
	4.8	Entrepreneurship												

Figure 2. Comparison of competence models for product development

The subsequent evaluation shows two groups of skills sets that are acknowledged specifically by competence models for product development:

- *Competences considered very frequent:* Understanding needs and setting goals, Disciplinary design (e.g. appropriate techniques, tools and processes), Communications, Attitudes, thoughts and learning, Analytical reasoning and problem solving, Enterprise and business context, Teamwork.
- *Competences considered often:* Defining function, concept and architecture, Development project management, Design process, Design for sustainability, safety, aesthetics, operability, other objectives, System thinking, Core Engineering fundamental knowledge, Utilization of knowledge in design, Entrepreneurship.

3.1.2 Competences for the engineering in the context of industry 4.0

Various studies and scientific publications anticipate changing engineering working systems in the context of industry 4.0 and describe the resulting competence requirements. Voigt et al. summarize existing findings of specific competences in the field of Product-Service Systems, arguing that this engineering working context is representative for industry 4.0. The authors state, that the existing empirical findings show the central role of *anticipatory thinking and combinatorial action in combination with advanced communicative and coordinative skills* (Voigt et al., 2015). Within another, more engineering specific expert study, the Acatech propose several areas for action for competence development. While addressing all phases of the engineering lifecycle (e.g. logistics, sales, order processing, production, service provision), the industry experts expect organizational changes especially in the field of product/service development and business model development (Abramovici and Herzog, 2016). The concrete needs for action are gathered in Table 2.

Table 2. Need for action (extract from Abramovici and Herzog, 2016)

Processes	Stronger synchronization between discipline-specific engineering processes
	Coordination between product development, service, production, sales, product operation processes
Methods	Simultaneous development of products and business models
	Methods for the product and service modelling
	Optimize processes with feedback information from the product use phase
IT-tools	Consistent use of knowledge management tools
	Tools for semantic analysis of data form product use
Organization	Flexible organizational structures
	Stronger cooperation with external partners
	Stronger cooperation between all lifecycle phases
Competences	Methodical competences for the engineering 4.0
	Establish new job roles for engineering 4.0
	Awareness for engineering 4.0

3.2 Analysing the work system "development of smart products"

Due to the topicality, identifying the vocational requirements in the addressed specific environment (RQ2) cannot be based on sound empirical observations (yellow field in Figure 1) up to now (Voigt et al., 2015). To answer the second research question, we follow a conceptual approach based on work system theory, which is helpful to understand a socio-technical system like product development at whatever level of detail is appropriate (Alter, 2012). On the one hand, specific job roles in the context of the development of smart products are examined with respect to the related new responsibilities (Chapter 3.2.1). On the other hand, the existing state of the art in design methodologies in the context of smart products is analysed. These design methodologies can be seen as an explication of expert knowledge with regard to the necessary processes and activities (Albers and Meboldt, 2007) in this field and therefore can be used instead of the missing best practice, normally depicted within interview studies in order to specify competence models.

3.2.1 New job roles in the context of the development of smart products

As deduced in Chapter 2.1, the development of smart products is accompanied with aspects of intelligent mechatronic systems, cyber-physical systems as well as product-service systems. Müller and Stark propose new job roles related to the development of products and services (Müller and Stark, 2014):

- *PSS Project Manager:* Consider service-orientation in design reviews, contracting with customer, customer involvement for need analysis, piloting, system approval, contracting suppliers, management of requirement exchange, agreement of service levels.
- *PSS Architect:* Customization of engineering processes, methods and tools, train colleagues, moderate PSS idea generation, requirements engineering on systems level, documentation of ideas and concepts, technical project management for downstream development, strategies to approach service oriented design.

3.2.2 Design Methodologies for the development of smart products

In order to identify the new processes and activities anticipated with the development of smart products, we conducted an analysis of design methodologies, related to intelligent mechatronic systems, cyber-physical systems and product-service systems. Furthermore, the scope was broadened towards the business model design perspective because the scientific discourse suggests a high relevance in the context of industry 4.0. We follow a research method proposed by Marques et al., who performed a comparative analysis of PSS design models not only on a process but also on a more detailed activity level. In order to compare the several process models, the activities were grouped into 12 categories (strategy, technology and market analysis, project management, stakeholder analysis, requirement definition, Conceptualization, Financial evaluation, Technical development (product), technical development (service and software), technical development (integration), environmental analysis and Launch/implementation) by similarity according to their names and contents. (Marques et al., 2016).

We adapt this method regarding the fact that we are solely looking for different activities compared to traditional product development methodologies. To avoid bias, the synthesis of processes and activities was evaluated and confirmed through a panel of specialists in this research area. The literature research conducted, focussed on meta-studies and mature research findings. The following sources were selected: Reference books: Gausemeier et al. 2015, Mousavi and Berger, 2015., Doctoral thesis: Dumitrescu, 2010, Köster, 2015, Müller and Stark, 2014, Publication in journal: Keating et al., 2008, Conference paper: Bossemeyer et al., 2014. The synthesis shows that only 4 of the 12 categories include new activities (extract):

- *Strategy:* Risk Management of Business Models, Configuration Management, Analysis of matches between provider and customer strategy, Definition of value creating lifecycle activities.
- *Stakeholder Analysis:* Establish relevant stakeholders and contextual issues, analyse their impact on systems goals and define possible strategies to manage it, Analysis of customer value creation and business environment, analyse customers and provider's capabilities, Structure the co creation.
- *Requirement definition:* Task and context analysis, definition of use cases, anticipation of system goals, consider flexibility of system goals, ascertaining business model requirements,
- *Conceptualization:* Extract factors that influence system goals, Identify the potential for self-optimization, identify cognitive functions, analyse possible architecture changes, strategies to modify structure and behaviour, Specification of partner networks, specification of adaption mechanisms, specification of risk allocation, Spatial allocation of processes and resources, specification of socio-technical interfaces.

Table 3 finally illustrates the results of the paper. Herein the certain competences are brought together. Considering the domain specific competences for product development shown on the right, the context specific dimensions are complemented to obtain a holistic view.

Table 3. Competences for the development of smart products

Product development	**Engineering industry 4.0**	**New Job roles**	**Design Methodologies**
Defining function, concept and architecture			Definition of value creating lifecycle activities
			Structure the co-creation
			Task and context analysis
			Definition of use cases,
			Consider flexibility of system goals,
			Extract factors that influence system goals
			Identify the potential for self-optimization,
			Identify cognitive functions,
			Analyse possible architecture changes,
			Strategies to modify structure and behaviour,
			Specification of partner networks
			Specification of risk allocation,
			Spatial allocation of processes and resources,
			Specification of socio-technical interfaces.
Development project management		Requirement exchange	Ascertaining business model requirements
		Technical project management for downstream development	
Design process	Synchronization between discipline specific engineering processes	Customization of engineering processes, methods and tools,	
	Process optimization with feedback information	Requirements engineering on systems level	
Design for x		Consider service-orientation in design reviews	
System thinking			
Core Engineering fundamental knowledge			
Utilization of knowledge in design	Use of knowledge management tools,		
Entrepreneurship	Simultaneous development of products and business models	Contracting with customer	Risk Management of Business Models
		contracting suppliers	
Understanding needs and setting goals		Customer involvement for need analysis	Establish relevant stakeholders and contextual issues, analyse their impact on systems goals and define possible strategies to manage it,
			Analysis of customer value creation and business environment
Disciplinary design (e.g. appropriate techniques, tools and processes)	Methodical competences for the engineering 4.0	Strategies to approach service oriented design	
Communications	Anticipatory thinking and combinatorial action in combination with advanced communicative and coordinative skills	Moderate PSS idea generation	
Attitudes, thoughts and learning		Train colleagues	
Analytical reasoning and problem solving			
Enterprise and business context			Analysis of matches between provider and customer strategy,
			Analyse customers and provider's capabilities,
Teamwork			

Using this model, instructional designers can systematically identify instructional goals and design suitable learning environments.

4 CONCLUSION AND OUTLOOK

This paper presents a conceptual approach to derive a competence model for the development of smart products. Thereby it makes a valuable contribution for education oriented design research, since there are no instructional goals or suitable competence models available in the domain of the development of smart products. Existing contributions are either not specific for product development or the context of industry 4.0. The next steps of research are concerned to an empiric grounding of the findings within 4 industrial case studies. Furthermore, the findings will be used to develop suitable learning environments for the development of smart products.

REFERENCES

Abramovici, M.; Herzog, O. (Eds.) (2016), *Engineering im Umfeld von Industrie 4.0: Einschätzungen und Handlungsbedarf* (acatech STUDIE), Herbert Utz Verlag, München, ISSN 2192-6174/ISBN 978-3-8316-4501-5.

Abramovici, M. (2014), "Smart Products". In: Luc Laperrière und Gunther Reinhart (Hg.): *CIRP encyclopedia of production engineering*. Heidelberg: Springer, S. 1–5.

acatech (Hrsg.) (2016), *Kompetenzentwicklungsstudie Industrie 4.0 – Erste Ergebnisse und Schlussfolgerungen,* München 2016.

Albers, A., Meboldt, M. (2007), "IPEMM – Integrated product development process management model, based on systems engineering and systematic problem solving." In: *International Conference of Engineering Design (ICED).*

Albers, A., Burkhard, N., Becke, C. (2012), "KaLeP: Karlsruher Lehrmodell für Produktentwicklung. Ein Ansatz zur Kompetenzerfassung in der Ingenieursausbildung", In: *Kompetenzen in der Kompetenzerfassung: Ansätze und Auswirkungen der Vermessung von Bildung*, edited by Michaela Pfadenhauer and Alexa-M. Kunz, 192. Weinheim, Basel, Beltz Juventa.

Alter, S. (2012), "The Work System Method: Systems Thinking for Business Professionals". In: *Proceedings of the 2012 Industrial and Systems Engineering Research Conference*, Orlando, Florida, 2012.

Anderl, R., Eigner, M., Sendler, U., Stark, R. (2012), *Smart Engineering. Interdisziplinäre Produktentstehung*. Berlin: Springer Vieweg (acatech DISKUSSION), 2012.

Baines, T., Bigdeli, A. Z., Bustinza, O. F., Shi, V.G., Baldwin, J. und Ridgway, K.: "Servitization: Revisiting the State-of-the-art and Research Priorities", In: *International Journal of Operations & Production Management*, 2016.

Beitz, W., Helbig, D. (1997), "Neue Wege zur Produktentwicklung - Berufsfähigkeit und Weiterbildung"; ersch. in: Beitz, W. (Hg.): *Schriftenreihe Konstruktionstechnik Berlin*; Berlin: TU Berlin, Schriftenreihe Konstruktionstechnik, Nr. 37 1997.

Bergenhenegouwen, G. J., ten Horn, H., Mooijman, E., (1996), "Competence development - a challenge for HR; professionals: core competences of organizations as guidelines for the development of employees". In: *Journal of European Industrial Training* 20/9, pp. 29-35.

Blessing, L. T. M.; Chakrabarti, A. (2009), *DRM, a design research methodology*. Dordrecht,, New York: Springer. ISBN 978-1-84882-587-1

Blum, M., (2004), *Product development as dynamic capability*, Phd-thesis, Universität der Bundeswehr München.

Bossemeyer, M. T., Aydin, K. T., Metzler, T., Lindemann, U. (2014), "Analysis of the systematic approach to develop cognitive products in academic research projects", in: *proceedings of the international design conference - Design 2014*, Dubrovnik - Croatia, May 19 - 22, 2014.

Conley, C. (2004), "Leveraging Design´s Core Competencies", In: *Design Management Review* 15(3): 45-51.

Crawley, E.F., Malmquist, J., Lucas, W., Brodeur, D.R. (2011), "The CDIO Syllabus v2.0 - An Updated Statement of Goals for Engineering Education", in: *Proceedings of the 7th International CDIO Conference*, Technical University of Denmark, Copenhagen, June 20 - 23, 2011.

Drechsler, S. (2016), *Competency Requirements implied by Standards and Guidelines for Mechanical Engineers in their day – to - day Activities*. Phd-Thesis, Karlsruhe, 2016.

Dumitrescu, R (2010), *Entwicklungssystematik zur Integration kognitiver Funktionen in fortgeschrittene mechatronische Systeme*. Universität Paderborn, Dissertation, 2010.

Edmonds, G. S.; Branch, R,C.; Mukherjee, P. (1994), A Conceptual framework for comparing Instructional Design Models, 1994, 10.1007/BF02298055

Erpenbeck, J., Rosenstiel, L.von (Hg.) (2007), *Handbuch Kompetenzmessung. Erkennen, verstehen und bewerten von Kompetenzen in der betrieblichen, pädagogischen und psychologischen Praxis*. 2., überarb. und erw. Aufl. Stuttgart, 2007.
Gausemeier, J.; Korf, S.; Porrmann, M.; Stahl, K.; Sudmann, O.; Vaßholz, M. (2014), "Development of Self-optimizing Systems". In: Gausemeier, J.; Rammig, F. J.; Schäfer, W.(Hg.), *Design Methodology for Intelligent Technical Systems*. Springer Berlin Heidelberg.
Geisberger, E., Broy, M. (Hg.) (2015), *Living in a networked world. Integrated research agenda, cyber-physical systems* (agendaCPS). München: Acatech National Academy of Science and Engineering; Herbert Utz Verlag GmbH (Acatech Study).
Goff, R., Terpenny, J.: "Engineering Design Education - Core Competencies", in: *Proceeding of Industrial and Manufacturing Systems Engineering Conference,* Iowa State University, 2012.
Hartig, J., Klieme, E. (2006), "Kompetenz und Kompetenzdiagnostik". In: Karl Schweizer (Hg.): *Leistung und Leistungsdiagnostik. Mit 18 Tabellen*. Berlin, Heidelberg: Springer Medizin Verlag Heidelberg, S. 127–143.
Keating, C. B.; Padilla, J. J.; Adams, K. (2008), "System of Systems Engineering Requirements: Challenges and Guidelines". In: *Engineering Management Journal 20 (4)*, S. 24–31. DOI: 10.1080/10429247.2008.11431785
Klauer, K. J., Leutner, D. (2012), *Lehren und Lernen. Einführung in die Instruktionspsychologie.* 2., überarb. Aufl. Weinheim: Beltz (Psychologie 2012). 2012.
Köster, M (2015), *Ein Beitrag zur modellbasierten Systempartitionierung industrieller Produkt-Service Systeme*. Phd-thesis, Bochum, 2015.
Kovacevic, A., (2008), "Competence Development on an International Product Design Course", in: *Proceedings Design 2008, Dubrovnik, Croatia, 2008*, pp 1383-1392.
Krathwohl, D. R., (2002), "A Revision of Bloom's Taxonomy: An overview. Theory into practice", Volume 41, Number 4, Autumn, pp. 212-218.
Kunrath, K, Cash, P & Li-Ying, J (2016), "Designer's Identity: Personal Attributes and Design Skills". In: *Proceedings of the 14th International Design Conference - Design 2016*. Design Society, pp. 1729-1740.
Lindemann, U. (2015), "Von der Mechatronik zu Cyber-Physical Systems", in: Lindemann, U.: *Handbuch Produktentwicklung*, Carl-Hanser Verlag, München, 2015.
Marques, C. A. N.; Mendes, G.; Oliveira, M. G.; Rozenfeld, H. (2016), "Comparing PSS Design Models Based on Content Analysis". In: *Procedia CIRP 47*, S. 144–149. DOI: 10.1016/j.procir.2016.03.068
Meier, H., Roy, R. Seliger, G. (2010), "Industrial-Product Service Systems - IPS²". In: *CIRP Annals - Manufacturing Technology 59*: 607-627. 2010.
Mousavi, M. R.; Berger, C. (2015), *Cyber Physical Systems. Design, Modeling, and Evaluation.* Cham: Springer International Publishing (9361).
Müller, P.; Stark, R. (Hg.) (2014), *Integrated engineering of products and services, layer-based development methodology for product-service systems*. Zugl.: Berlin, Techn. Univ., Diss., 2013. Stuttgart: Fraunhofer Verl. (Berichte aus dem Produktionstechnischen Zentrum Berlin).
Riel, A. (2010), "Integrated Design – A Set of Competences and Skills Required by Systems and Product Architects". In: Andreas Riel (Hg.): *Systems, Software and Services Process Improvement*. 17th European Conference, EuroSPI 2010, S. 233–244.
Rijsdijk, S. A. and Hultink, E.J. (2007), "How Today's Consumers Perceive Tomorrow's Smart Products" IN: *ERIM Report Series Reference No. ERS-2007-005-ORG*. Available at SSRN: https://ssrn.com/abstract=968850
Voigt, B. F.; Süße, T.; Wilkens, U. (2015), "Entwicklung von Kompetenzen für Industrie 4.0 im Rahmen eines Planspielszenarios. Simulation und Evaluation". In: Meier, H.: *Lehren und Lernen für die moderne Arbeitswelt.*
Weinert, F. E. (1999), *Concepts of competence. Contribution within the OECD project Definition and Selection of Competencies: Theoretical and Conceptual Foundations (DeSeCo).* München: Max Planck Institute for Psychological Research, 1999.
Zink, K. J.; Eigner, M. (2013), *Humanfaktoren in der Produktentwicklung*. Kurzbericht.