Engineering Education for Industry 4.0
Challenges, Chances, Opportunities

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World Engineering Education Forum 2015
I. Scientific Programming - the New Latin for Engineers
   - On the way to “Industry 4.0” – the status quo
   - Why engineers have to be able to “speak code”
   - Implications for engineering education

II. Entrepreneurship - the (not so New) Motor for the Economy
   - About the connection between innovation and entrepreneurship
   - About entrepreneurship in Industry 4.0
   - New paradigms of innovation: Open innovation
   - Implications for engineering education

III. Learning Analytics – the New Understanding of Learning Processes
   - Why learning analytics will change the way we teach
   - Advantages and challenges of big data analysis in education
   - Reshaping education: Vision or Soap-Bubble?

IV. Summary and Outlook
Scientific Programming - the New Latin for Engineers

**Breakthroughs - A new era of artificial intelligence**

- **Communication technology**
  bandwidth and computational power

- **Embedded systems**
  miniaturization

- **Semantic technologies**
  information integration

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Google Car
2012

Watson
2011

22.09.2015
S. Jeschke
Scientific Programming - the New Latin for Engineers

Breakthroughs - Everybody and everything is networked

**Communication technology**
bandwidth and computational power

**Embedded systems**
miniaturization

**Semantic technologies**
information integration

- **Swarm Robotics**
- **Team Robotics**
- **Smart Factory**
- **Smart Grid**
- **Car2Infrastructure**
“Information Revolution”

Everybody and everything is networked. - Big Data & Cyber-Physical Systems

“Internet of Things & Services, M2M or Cyber Physical Systems are much more than just buzzwords for the outlook of connecting 50 billions devices by 2015.”
Dr. Stefan Ferber, Bosch (2011)

Weidmüller, Vision 2020 - Industrial Revolution 4.0
Intelligently networked, self-controlling manufacturing systems

Vision of Wireless Next Generation System (WiNGS) Lab at the University of Texas at San Antonio, Dr. Kelley

1st industrial revolution
Mechanical production systematically using the power of water and steam

Power revolution
Centralized electric power infrastructure; mass production by division of labor

Digital revolution
Digital computing and communication technology, enhancing systems’ intelligence

Information revolution
Everybody and everything is networked – networked information as a “huge brain”

around 1750
around 1900
around 1970
today
Integrating complex information from multiple heterogeneous sources opens multiple possibilities of optimization: e.g. energy consumption, security services, rescue services as well as increasing the quality of life.

Back to: The earth converted into a huge “brain”... (Tesla 1926)

... and more
Scientific Programming - the New Latin for Engineers

“Informatics is the new latin”...

(Mechanical) Engineering

Virtual Production
Product Design
E-Engineering
Digital Machine Construction
Integration

Becomes a Major Part of ME

Web-Based Solutions
Decentralization
Digital Trial & Error
No Language/Time Barriers
Internet of Things
Cyber-physical Systems
System Security
Smart Data/Big Data

The Employee of Industry 4.0

Orientation Towards Digitalization

ME

Scientific Programming

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0) 2009: Truck robot platoons – **distributed** intelligence

→ **The KONVOI project (several institutes from RWTH & industry partners)**

- 2005-2009
- automated / partly autonomous transportation e.g. by electronically coupling trucks to convoys
- several successful tests with trucks: Chauffeur, KONVOI, SARTRE (EU), Energy-ITS (Japan), ...

→ Adv. driver assistance system for trucks
→ short distances between vehicles of approx. 10m at a velocity of 80 km/h
→ Energy-ITS: 4m ! (2013)

→ KONVOI:
  - Car2infrastructure components!
  - Model of multi agent systems

→ expected improvements: beyond safety, reduction of fuel consumption and gained road space
Organization forms on demand – individualized by client - initialized by product

- Heterogeneous player modeled as multi agent concept
- Models from biology and social sciences
- Basis on Autopoiesis & embodiment theory

Product agitates as “super-agent”:
- Plans production and transportation steps
- Requests service from agents
- Negotiates with other products for agent-resources

Transport unit
Production unit
Virtual service provider
Outside world
Fabrication
Robots are no longer locked in work-cells but cooperate with each other and/or with humans.

*machine-machine cooperation*

*human-machine-machine interaction in the X-Cell*

Hybrid planning for real-time capability integrates several robots and/or human and robot in assembly task („assembly by disassembly“), split into „online-offline“ for real-time capabilities.
Mobile transportation robots from flexible routing

Competencies:
- localization & navigation
- computer vision
- adaptive planning
- multi agent strategies
- sensory & hardware

Competitions robocup:
2012: 0 points in World Cup
2013: 4th in World Cup
2014: Winner of the GermanOpen
2014: Winner of the World Cup
new League High Score

Critical factors for success:
- Totally decentralized
- No „hard coded components“
- Strong cooperation
- Re-planning during tasks

http://www.carologistics.org/
Scientific Programming - the New Latin for Engineers

Leading to: Interdisciplinary science and education

New fields of work

- Social Robotics
- Augmented reality
- Virtual reality
- Natural language communication
- Human-Maschine Interaction

- Autonomous systems
- Autonomous flying
- Virtual reality
- Lightweight robots
- Car2X
- Smart Logistics
- Swarm robotics
- Cloud logistics
- Autonomous intralogistics

- Business Computing
- Risc analysis
- Data Analysis

- Uncanny valley
- Antropomorphism
- ...?
Excellence through Interdisciplinarity

- Without interdisciplinarity, there is no innovation.
- Development of highly complex, socio-technical systems requires the collaboration of various academic disciplines.
- Future Engineers need the skills to “look beyond their own nose”.

Adaptability to rapid innovation cycles

- The “half-life” of knowledge sector is shortening rapidly.
- Students need less detailed specialized content than the ability of life long learning.
- Future Engineers need the skills to adapt to changes quickly.

Survival in Industry 4.0 requires IT skills

- IT is the main driver of innovation in future industrial contexts
- Independent of the specialization, engineers must have the basic knowledge and understandings of others
- Future Engineers need to be able to “speak code”.

Scientific Programming - the New Latin for Engineers
Implications for Future Engineering Education

22.09.2015
S. Jeschke
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IV. Summary and Outlook
Innovations in 4.0

The two ways of innovation

- Mobility
- Urbanization
- Internet of things
- New education
- New ecology
- Globalization
- Big Data
- New health paradigms
- Individualization
- Connectivity
- Autonomous intelligent Systems
- Cyber physical systems
- Industry 4.0
- Revolutionary
- Evolutionary
- New ecology
- New health paradigms
- New education
- Internet of things
- Urbanization
- Mobility

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Innovations in 4.0

If innovation cycles become faster, we need more enterprises!

Innovations in 4.0

If innovation cycles become faster, we need more enterprises!

What to Do?
How to cope...

Innovations in 4.0
Vendor change?

Characteristics of industrial revolutions: The vendor change

1st industrial revolution
Mechanical production systematically using the power of water and steam

Power revolution
Centralized electric power infrastructure; mass production by division of labor

Digital revolution
Digital computing and communication technology, enhancing systems’ intelligence

Information revolution
Everybody and everything is networked – networked information as a “huge brain”


Nevada issued Google a license: the world’s first driverless car to drive on public streets (2012)

latest version of Google’s self driving car (Huffington Post, 28.5.2014)

first sightings of the iCar (?) in New York and San Francisco (16.2.2015)

Ford 012C concept car 2012, designed by Newson now at Apple (1999)

Apple Inc.
Innovations in 4.0

Innovation comes from fresh minds!

- Founding a new existence
- Finding out about market borders
- System-oriented broad potential
- Capital risks
- Start-Ups

Innovative Ideas

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Entrepreneurship - the Motor for the Economy

The question is – how do we teach them to be like that?!

Classical Entrepreneurs needed Classical Skills...

Entrepreneurial Skills
- accepting uncertainty
- ability of taking risks
- innovative
- change-oriented
- persistent

Technical Skills
- broad !!
- high-speed adaptive
- environmental observation
- design & individualization
- communication-oriented
- Human maschine interaction

Management Skills
- decision-making
- fast and based on knowledge as well as on instinct
- leadership skills, motivating
- marketing, financial aspects, selling, ...

But is that ENOUGH to prepare for industry 4.0?
Entrepreneurship - the Motor for the Economy...
From „1 Man 1 Sign“ to the „Entrepreneur Village“

Communication technology
bandwidth and computational power

Semantic technologies
information integration

Outsourcing comes of age:
The rise of collaborative partnering

around 4000 BC
around 1900
around 1970
today

1st entrepreneurship revolution
1 man show + raw materials

2nd entrepreneurship revolution
1 man show + basic communication and information

3rd entrepreneurship revolution
1 man show + extensive communication and information

4th entrepreneurship revolution
1 man show + a village’s support in communication and information

[PricewaterhouseCoopers 2008, MacCormack et al. 2007]
Entrepreneurship - the Motor for the Economy

Open Innovation – success needs participation and collaboration

Access to crowd-sourcing, overcoming the “local search bias”...

Open Innovation...
...assumes that firms can and should use external ideas [and] internal ideas, and internal and external paths to market, as the firms look to advance their technology (Chesbrough 2003)

... leading to new – more social - challenges as:
- To to keep an innovation advance if everything is “open”?
- thrust, IP-rights, ownership
- How to build up a specific organizational culture with its player constantly changing?
- ...

www.psicorp.com/open_innovation/index.html
SMEs and LEs and Freelancer will be brought together for a more robust system that includes outsourcing, using common logistics, open sources...

New types of employment, New business-models – examples: globalization, personalization, Pay by the hour, ... with strong consequences to the whole complex of “work and life”, stability, predictability, etc.

In particular, high-wage countries are under pressure.
More than 80 professions are changed or newly added since 2010 in Germany in order to fulfil the demand of the industry regarding necessary business and society changes. 

Source: http://www.bibb.de/

Andreas Schneider, Head of Education, TRUMPF Group

„Even if the content of an apprenticeship already changed regarding Industry 4.0 – it does not help if the teacher stays at Industry 1.0“

Source: http://heise.de/-2792105

Some New Professions & Studies

Knowledge Management, Social Media Manager, Media Technologist, Mechatronics Engineers, Data Analyst, IT Security, 3D-Mind & Media, ...

Source: http://www.alumniportal-deutschland.org/

New professions are not enough to satisfy the demand for new innovations. Entrepreneurs are innovators which have to fill the gap.

Support for entrepreneurs

Entrepreneurship Competition => 3.16 Million Euro through 124 competitions in Germany (2014)
Mentoring => available for free through entrepreneurship competitions & available at universities
Business incubators => more than 500 at Germany; more than 10,000 at Europe
Grants => EXIST (government support programme) up to 150,000 Euro for each start-up
The HKUST, the RWTH and a US university...

- Joint MASTER program
- International, on three continents
- Project oriented, mixed teams
- Based on the model of HKUST “Technology Leadership and Entrepreneurship” (http://tle.seng.ust.hk/)

- Joint core curriculum
- Partly in-class lectures, partly MOOCs
- Location/residence of students: “2 + 1 + 1” or “1+1+1+1” (2 semester at home university + one at each of the partner A and B)
- 30 students per facility
- entrance requirement: BA in a field of engineering or natural sciences
- Optional features due to the regulations of the three partners (e.g. credit point rules, titles of program etc. ...)

Example 1: international joint program of Entrepreneurship
Entrepreneurship - the new Motor for the Economy

Example 2: smooth integration into existing curriculum

Topic of the Business Simulation ROBOFLEX
ROBOFLEX is a set of business simulations of enterprises and communication strategies. The students aim to develop autonomous vehicles based on Lego Mindstorms NXT.

location and time dependent learning, communicating and briefing

knowledge exchange, team meetings and intensive advisory through the research assistants via direct communication during office hours, tutorials and workshops

Winner’s video

Winners of ROBOFLEX
New Business Thinking

- Above the classical basic skills to manage development projects, Future Entrepreneurs need additional skills in particular in leadership, decision making, ...
- They need to know how to communicate business ideas to different stakeholders.
- Future Engineers need to know, how to collaborate in the “global village”.

Taking Risks and Dealing with Uncertainty

- Uncertainty cannot be managed. Even the best prediction will end up as “only partially correct”. And... good predictions need time which is lost for other things.
- Future Engineers need be to unterrified – and capable to adapt to changes quickly and through broad competencies.

Bursting with Creativity

- When speed of innovation cycles increases, creativity becomes the “new gold”.
- Students need the ability to critically assess issues and develop sound, responsible, and creative solutions.
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IV. Summary and Outlook
Learning Analytics – the New Understanding of Learning Processes

... MOOCs around the World: a boom in about 3 years

North America
- Udacity
- Coursera
- edX
- Khan Academy
- Udemy
- P2PU
- FutureLearn
- Open2Study
- OpenLearning
- Vocedi

Europe
- Change.mooc.ca
- CCK08/09/10/12
- LAK 11/12/13
- PLENK 2010
- OpenupEd
- Iversity
- OpenLearn

Rest of World
- Japan: Schoo
- Malaysia & Indonesia: MOOCs on Entrepreneurship
- Australia: openlearning, open2study
- Brasil: veduca

Learning Analytics – the New Understanding of Learning Processes

Higher Education... the Usual Recipe 😊

- Online Distribution of Learning Material
- Group-/Peer-Based Learning Activities
- Feedback /Peer Exchange
- Exam & Certificates
- Face to Face Teaching
- Lab Experience
Learning Analytics – the New Understanding of Learning Processes
Higher Education... the „New Way“

Face to Face Teaching

Online Distribution of Learning Material

Group-/Peer-Based Learning Activities

Exam & Certificates

Feedback /Peer Exchange

Lab Experience
Learning Analytics – the New Understanding of Learning Processes

Okay, MOOCs are nice, BUT... the paradigm shift in education

Accessibility

Making education smart and individualized

Log on and learn

A PC in every class!

Making education widely available

4th industrial revolution

PCs
1990s

The Internet
2000s

Cloud and Smart Phones
2012s

Adaptive Technology
now

IMA ZLW IfU

25.08.2015
S. Jeschke
“Big data is the term for a collection of data sets so large and complex that it becomes difficult to process using on-hand database management tools or traditional data processing applications. The challenges include capture, curation, storage, search, sharing, transfer, analysis and visualization.”

“Big Data refers to technologies and initiatives that involve data that is too diverse, fast-changing or massive for conventional technologies, skills and infrastructure to address efficiently. Said differently, the volume, velocity or variety of data is too great. But today, new technologies make it possible to realize value from Big Data.”

“Every day, we create 2.5 quintillion bytes of data - so much that 90% of the data in the world today has been created in the last two years alone. This data comes from everywhere: sensors used to gather climate information, posts to social media sites, digital pictures and videos, purchase transaction records, and cell phone GPS signals to name a few. This data is big data.”
Learning Analytics – the New Understanding of Learning Processes

Big Data induce “intelligence”: from Big Data to Smart Data...

The Big Data analysis pipeline...

- ... transfers big data (many...) into smart data (meaningful data)
- ... accumulates intelligence from information fragments
- ... is a pipeline of aggregating (artificial) intelligence.

Acquisition/Recording ➔ Extraction/Cleaning/Annotation ➔ Integration/Aggregation/Representation ➔ Analysis/Modeling ➔ Interpretation

BIG DATA + SMART DATA ➔ INTELLIGENCE/DECISION/INSTRUCTION
Learning Analytics: “Transparency is the new green!”
An approach towards the realization...

The pipeline for Learning Analytics in a nutshell

**Analyze**
- Show data to students
- Track the individual development

**Predict**
- Predict future developments
- Show potential problems

**Implement**
- Develop best learning strategy
- Adjust standards for assessments
Learning Analytics – the New Understanding of Learning Processes
The Future: Adaptive Learning Environments

Learning Analytics is the key for future adaptive learning environments

Graph theory

Differential equation

Arithmetic

Linear algebra

Statistics

Student’s performance for some mathematical topics

Student

Student’s Content

Adaptation Engine

Predictive Model

Student’s Performance

Differential equation

Arithmetic

Linear algebra

Statistics

Graph theory

Last Week

This Week

Student’s performance for some mathematical topics
The TU Graz has developed an application for learning mathematics with integrated learning analytics. The teacher can see the success or failure of every student for each topic. The exercise generator is aware of the student’s progress.


Moreover, normal learning management systems (LMS) like e.g. Moodle are plugins and extensions able to get an insight on how the students learn e.g. similar to the heat-map on the left side.
Learning Analytics – the New Understanding of Learning Processes
First Outcomes and Results

... from the Learning-Analytics Tool LeMo

What is currently being measured?
- Activity per Workday and Learning Object
- Timely order of task completion
- Learning-Path (same color = same resource)

Questionnaires
- General questions
- User Behavior
- User Interests

Explorative Visualization:
Evaluation of both real-life classes and virtual learning environments

Results
- (Students’) Willingness to be analyzed
- Willingness to adapt to reflection results
- Willingness to give constructive feedback
Learning Analytics – the New Understanding of Learning Processes
Towards democratized, diverse and globalized education

<table>
<thead>
<tr>
<th>In the tradition of the other industrial revolutions</th>
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<tbody>
<tr>
<td><strong>Society</strong></td>
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<tr>
<td>Reusability of content</td>
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<td>Optimization of Teaching</td>
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<td>Improvement of future courses</td>
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<td>Early warning-system for knowledge gaps</td>
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<td><strong>Individual</strong></td>
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<td>Individualization</td>
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<td>Prediction of Performance</td>
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<td>Adaption to any knowledge level</td>
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<td>Control over learning process</td>
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<td>possibility to learn at home</td>
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<tr>
<td><strong>Non-privileged</strong></td>
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<tr>
<td>All you need is a web connection</td>
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<td>(Higher) Education becomes affordable</td>
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<td><strong>Special Needs</strong></td>
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<td>Better insights into habits of slow learners</td>
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<td>Combine with specific learning software</td>
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<tr>
<td>Optimal encroachment of learning channels</td>
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<tr>
<td>possibility to learn at home</td>
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</tbody>
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[Kindeswohl Berlin, 2015/ Gradireland, 2013]
Individualization
- Institutions and Teachers must be open-minded for such new concepts and also gain the necessary competencies
- Digital Natives: The future students want these concepts. They are used to “fits-me” content. If this is not offered, they are likely to lose interest.

Curriculums & Certificates
- The „traditional“ business model of universities becomes disrupted.
- The curriculums must be flexible in order to allow e.g. their shortening or extension according to the individual student needs.
- The recognition of MOOC credits from various education providers is essential. Here, new quality measurements are needed to support the process of certificates.

Access, Privacy and Transparency
- New rules: Who can, when and where, access the student’s data e.g. in the cloud, in order to execute the necessary analytics?
- Which privacy issues occur and how are we going to deal with them?
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IV. Summary and Outlook
Summary

... in three steps!

We are in the middle of a 4th industrial revolution.

IT & artificial intelligence

Systems and technology are changing rapidly. New HMI will to a central topic.

Big Data & Learning Analytics

Big Data technology is the entrance into a new way of supporting individualized learning processes for all.

Innovation & Entrepreneurship

Entrepreneurship changes its appearance. The Entrepreneurs of today differ from the ones before.
Thank you!

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### Prof. Dr. rer. nat. Sabina Jeschke

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>1968</td>
<td>Born in <strong>Kungälv/Schweden</strong></td>
</tr>
<tr>
<td>1994</td>
<td><strong>NASA</strong> Ames Research Center, Moffett Field, <strong>CA/USA</strong></td>
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<tr>
<td>10/1994</td>
<td>Fellowship „Studienstiftung des Deutschen Volkes“</td>
</tr>
<tr>
<td>1997</td>
<td>Diploma Physics</td>
</tr>
<tr>
<td>1997 – 2000</td>
<td>Research Fellow, <strong>TU Berlin, Institute for Mathematics</strong></td>
</tr>
<tr>
<td>2000 – 2001</td>
<td>Lecturer, <strong>Georgia Institute of Technology, GA/USA</strong></td>
</tr>
<tr>
<td>2001 – 2004</td>
<td>Project leadership, <strong>TU Berlin, Institute for Mathematics</strong></td>
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<tr>
<td>04/2004</td>
<td>Ph.D. (Dr. rer. nat.), <strong>TU Berlin, in the field of Computer Sciences</strong></td>
</tr>
<tr>
<td>2004</td>
<td>Set-up and leadership of the Multimedia-Center at the <strong>TU Berlin</strong></td>
</tr>
<tr>
<td>2005 – 2007</td>
<td>Juniorprofessor „New Media in Mathematics &amp; Sciences“ &amp; Director of the Multimedia-center MuLF, <strong>TU Berlin</strong></td>
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<td>2007 – 2009</td>
<td><strong>Univ.-Professor</strong>, Institute for IT Service Technologies (IITS) &amp; Director of the Computer Center (RUS), Department of <strong>Electrical Engineering</strong>, University of <strong>Stuttgart</strong></td>
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<td>since 06/2009</td>
<td><strong>Univ.-Professor</strong>, Head of the Institute Cluster IMA/ZLW &amp; IfU, Department of <strong>Mechanical Engineering</strong>, <strong>RWTH Aachen University</strong></td>
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<tr>
<td>since 10/2011</td>
<td><strong>Vice Dean</strong> of the Department of <strong>Mechanical Engineering</strong>, <strong>RWTH Aachen University</strong></td>
</tr>
<tr>
<td>since 03/2012</td>
<td><strong>Chairwoman VDI Aachen</strong></td>
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<tr>
<td>since 05/2015</td>
<td><strong>Supervisory Board of Körber AG</strong>, <strong>Hamburg</strong></td>
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