Engineering Education for Industry 4.0
Challenges, Chances, Opportunities

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Agenda

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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**Watson**

2011

**Google Car**

2012
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**
- **Car2Infrastructure**
- **Smart Grid**

**Breakthroughs**
- Everybody and everything is networked
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)

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

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

„local“ to „global“

around 1750

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

around 1900

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

around 1970

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

today

Information revolution
Everybody and everything is networked – networked information as a “huge brain”
Not restricted to industry: cyber physical systems in all areas

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

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

... and more

Building automation

Smart metering

‟house 4.0”

Smart grid

Room automation

‟power grid 4.0”

Smart environment

‟mobility 4.0”

‟health 4.0”

‟education 4.0”
Scientific Programming - the New Latin for Engineers
“Informatics is the new latin”...

(Mechanical) Engineering

Virtual Production
Product Design
Digital Machine Construction
Integration

E-Engineering

The Employee of Industry 4.0

Orientation Towards Digitalization

ME ➔

Scientific Programming

SP ➔

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

Informatics is the new latin…
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), ...

- Advanced 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

© Daniel Ewert 2013
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

- Natural language communication
- Virtual reality
- Augmented reality
- Human-Maschine Interaction
- Social Robotics
- Antropomorphism
- Uncanny valley
- Automated driving
- Lightweight robots
- Autonomous systems
- Autonomous flying
- Smart Logistics
- Cloud logistics
- Swarm robotics
- Car2X
- Autonomous intralogistics
- Business Computing
- Risc analysis
- Data Analytics
- ...?
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
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IV. **Summary and Outlook**
Innovations in 4.0
The two ways of innovation

“Innovations are divided into two categories:

- **Evolutionary innovations** (continuous or dynamic evolutionary innovation) that are brought about by many incremental advances in technology or processes and

- **Revolutionary innovations** (also called discontinuous innovations) which are often disruptive and new.”

**IMPORTANT:**
- In times of Industrial Revolutions, the revolutionary innovations dominate.
- In the times between, the evolutionary innovations dominate.
The innovators’ dilemma

Revolutionary

Evolutionary

Evolutionary innovations:

- Improvement and optimization of an already existing product or process
- Changes 'locally'

Mainly carried out by market newcomers

Revolutionary innovations:

- Something „really new“
- Characterized by categorial changes and with strong consequences for the society, 'globally'

Mainly carried out by established players

The more professional organization are, the stronger they tend to remain in their traditions since...

- ... management structure is organized in such a way that it „reproduces“ itself
- ... clients' sugestions always address traditional ways
- ... self-affirmation feedback...

Standard management methods as TQM, CIP(KVP), Kaizen, standards, lean management, etc. address evolutionary processes

- ... hampering categorial changes, system changes and disruptive changes
Joseph A. Schumpeter (1883-1950)
- Austrian-American economist
- Harvard professor
- One of the most influential economists of the 20th century

Schumpeter: In this turbulent environment, innovation is the new old magic formula to survive, act and compete efficiently in the long run.

Creative destruction:
“Process of industrial mutation that
- ... incessantly revolutionizes the economic structure from within,
- ... incessantly destroying the old one,
- ... incessantly creating a new one”
[http://www.haufe.de/ 2015]

→ Destruction is necessary.
It is not a „system failure“
but a necessity for reforms.

“Creative destruction“
First definition of disruptive, revolitional innovations
About Innovation Cultures in 4.0

Innovation – A question of culture?!

Since the 1960s:
- research on organizational cultures in respect to innovation, “innovation culture”

Breakthrough of the “culture concept” in the 1980s

Hofstede’s “cultural dimensions theory” (1980)
- 5 cultural dimensions
- Still most cited European social scientist
- Critics addresses mainly the particular dimensions and the measurement process, but not the general approach.

Organizational culture...
- ... transfers the concept of culture from cultural anthropology (national cultures) to organisations.
- ... represents the collective values, beliefs and principles of organizational members.
- ... is a product of such factors as history, product, market, technology, and strategy, type of employees, management style, and national culture.

Innovation culture:
Innovation culture describes a specific type of organisational culture addressing the generation of innovation in the organisation.

Hofstede (1991):
Culture is the collective programming of the mind which distinguishes the members of one group from another.

[Wikipedia, 2015]
More prominent approaches...

**Hall’s anthropologist and cross-cultural approach**
- The concept of social cohesion
- Description of how people behave and react in different types of culturally defined personal space
- **Single vs. multi tasking**: Monochronic vs. polychronic time (1959)
- **Context orientation** (high vs. low context cultures; 1976)
- 4 cultural dimensions in total

**Dülfer’s economical and synoptic cultural approach**
- Cultural dimensions summarized in environmental layers: **man-made vs. natural environment**
- In the long term, lower layers (natural environment, technology) evolutionarily influence the upper layers

Edward T. Hall (1976): **... a culture's tendency to use high-context messages over low-context messages in routine communication.**

Eberhard Dülfer (1974): **... the model reveals, what influences and relationships the decision-makers have to consider.**
Innovations in 4.0

Innovation cycles become faster...

Innovations in 4.0 ... and faster!

What to Do? How to cope...

From the Basics to Innovation in 4.0

Speed and complexity of revolutional innovations

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

1st Industrial Revolution
Mechanical production systematically using the power of water and steam
Around 1750

2nd Industrial Revolution
Taylorism, Mass production by division of labour, networked electrical power
Around 1900

3rd Industrial Revolution
Digital computing and communication technology, IT-Automation, Industrial robots, SPS
Around 1970

4th Industrial Revolution
Everybody and everything is networked, Cyber Physical Systems
Today

First power loom, 1784
First assembly belt production, slaughterhouse of Cincinnati, 1870
First memory programmed control (SPS), Modicon 084, 1969
Cyber Physical System, 2011
Characteristics of Industrial Revolutions:

**The vendor change**

- **1st Industrial Revolution**
  - Around 1750
  - Mechanical production systematically using the power of water and steam

- **Power Revolution**
  - Around 1900
  - Centralized electric power infrastructure; mass production by division of labor

- **Digital Revolution**
  - Around 1970
  - Digital computing and communication technology, enhancing systems’ intelligence

- **Information Revolution**
  - Today
  - Everybody and everything is networked – networked information as a “huge brain”

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**Car specialists? – No.**

- Connectivity & data specialists.
- Energy & sensor specialists.

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For other dimensions of “take overs”, see keynote “Innovation 4.0”:
Innovations in 4.0
The vendor change around „cars“

Characteristics of Industrial Revolutions:
The vendor change

1. **First Industrial Revolution**
   - Around 1750
   - Mechanical production systematically using the power of water and steam

2. **Power Revolution**
   - Around 1900
   - Centralized electric power infrastructure; mass production by division of labor

3. **Digital Revolution**
   - Around 1970
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4. **Information Revolution**
   - Today
   - Everybody and everything is networked – networked information as a “huge brain”

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**An autonomous car is more like a computer on wheels than a car which includes one or many computers.**

- **Google**
  - First autonomous car with street license, 2012

- **Apple Inc.**
  - Ford 021C concept car 2012, designed by Newson now at Apple (1999)

- **Tesla**
  - Tesla X 2015, other Teslas since 2006; Forbes: “most innovative enterprise”

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For other dimensions of “take overs”, see keynote “Innovation 4.0”:
Innovations in 4.0

Innovation comes from fresh minds!

Capital risks

Start-Ups

Innovative Ideas

Founding a new existence

Finding out about market borders

System-oriented broad potential
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

Let’s Partner Up

Outsourcing comes of age:
The rise of collaborative partnering

around 4000 BC
1st entrepreneurship revolution
1 man show + raw materials

around 1900
2nd entrepreneurship revolution
1 man show + basic communication and information

around 1970
3rd entrepreneurship revolution
1 man show + extensive communication and information

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

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

... 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, predictibility, etc.

Freelancer

- flexible
- specialized
- linked

SMEs

- innovative
- creative
- specialized

LEs

- robust
- stable
- international

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/

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/

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

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.

Winner’s video

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

Winners of ROBOFLEX
... leading the Entrepreneurs of the future:

Implications for Future Engineering Education

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.
Agenda

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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
- udemy
- change.mooc.ca
- CCK08/09/10/12
- LAK 11/12/13
- PLENK 2010...
- ...

**Europe**
- The Open University
- Future Learn
- OpenUpEd
- iversity
- OPCO12
- OPEN ELP
- HPI Plattner Institut

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

North America

Europe

Rest of World
Learning Analytics – the New Understanding of Learning Processes

Higher Education... the Usual Recipe 😊

- Face to Face Teaching
- Distribution of Learning Material
- Group-/Peer-Based Learning Activities
- Feedback /Peer Exchange
- Exam & Certificates
- 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

A PC in every class!

Log on and learn

Making education widely available

4th industrial revolution

PCs
The Internet
Cloud and Smart Phones
Adaptive Technology

1990s
2000s
2012s
now

25.08.2015
S. Jeschke
Learning Analytics – the New Understanding of Learning Processes
Let’s ask Google

“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.

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<table>
<thead>
<tr>
<th>Acquisition/Recording</th>
<th>Extraction/Cleaning/Annotation</th>
<th>Integration/Aggregation/Representation</th>
<th>Analysis/Modeling</th>
<th>Interpretation</th>
</tr>
</thead>
</table>

**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

- Analyse
  - 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

Student’s performance for some topics

Student’s Content

Graph theory
Arithmetic
Linear algebra
Differential equation
Statistics

Predic- tive Model
Adap- tion Engine

Student

0
20
40
60
80
100

Last Week
This Week
Learning Analytics: “Transparency is the new green!”

Neuroevolution to Evolve Artificial Intelligences

A method which imitate the evolution of biological systems in nature

- (0) Start: Random
- (1) Fitness
- (2) Species & Choice
- (3) Reproduction
- (4) Mutation
- (5) New Population

E-Learning Trends & Recommendations for Teachers
ZLW RWTH AC

- Teachers receive adaptive recommendations regarding their classes’ requirements
- Analyze Massive IoT Data of Classes
- Embedded Assessments

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

[Elkina et al., 2015 / Clow, 2015]
In the tradition of the other industrial revolutions

### Society
- Reusability of content
- Optimization of Teaching
- Improvement of future courses
- Early warning-system for knowledge gaps

### Non-privileged
- All you need is a web connection
- (Higher) Education becomes affordable
- Flexibility
- Independence from real-life teachers

### Individual
- Individualization
- Prediction of Performance
- Adaption to any knowledge level
- Control over learning process
- Possibility to learn at home

### Special Needs
- Better insights into habits of slow learners
- Combine with specific learning software
- Optimal encroachment of learning channels
- Possibility to learn at home

[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 be a central topic.

4th industrial revolution

Innovation & Entrepreneurship

Big Data & Learning Analytics

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

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

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since 03/2012 Chairwoman VDI Aachen
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