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**

Breakthroughs - A new era of artificial intelligence

Communication technology
bandwidth and computational power

Embedded systems
miniaturization

Semantic technologies
information integration

Watson 2011

Google Car 2012

Breakthroughs - Everybody and everything is networked

Communication technology
bandwidth and computational power

Embedded systems
miniaturization

Semantic technologies
information integration

Car2Infra-structure

Swarm Robotics

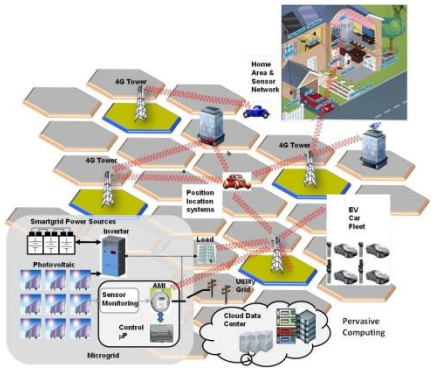
Team Robotics

Smart Grid

Smart Factory

“Information Revolution”

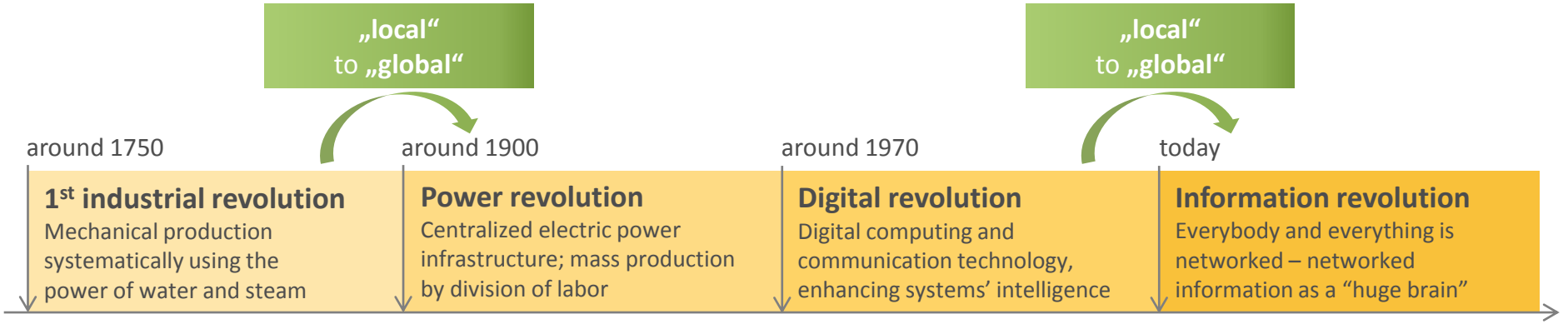
Everybody and everything is networked. - Big Data & Cyber-Physical Systems



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

> “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, Vission 2020 - Industrial Revolution 4.0
Intelligently networked, self-controlling manufacturing systems)



Not restricted to industry: cyber physical systems in all areas

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

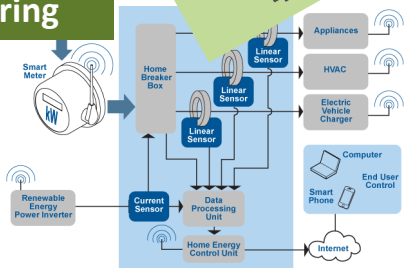
Integrating complex information from **multiple heterogeneous sources** opens multiple possibilities of **optimization: e.g. energy consumption, security services, rescue services** as well as **increasing the quality of life**

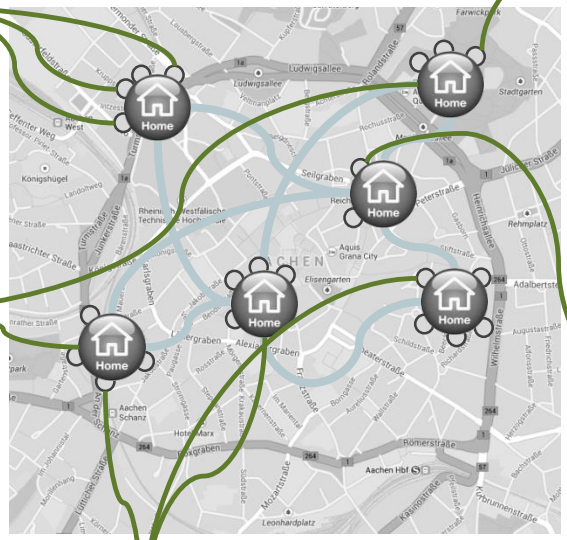
Building automation

„house 4.0“

Smart metering

„metering 4.0“



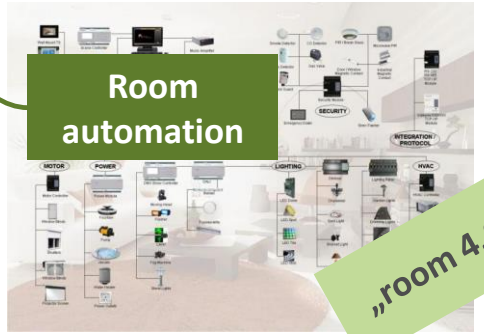


Smart grid

„power grid 4.0“

Smart environment

Room automation



„room 4.0“

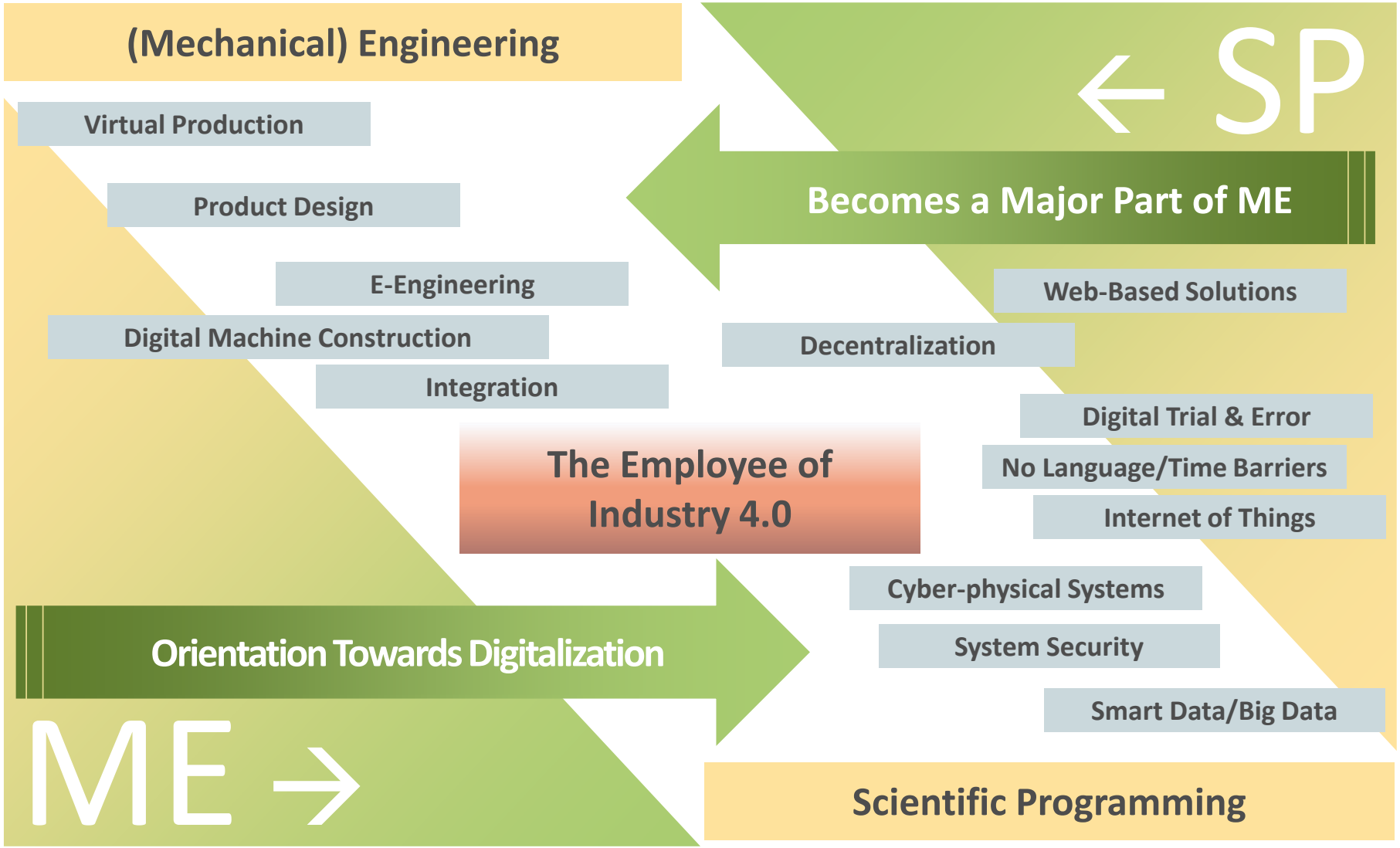
„mobility 4.0“

„health 4.0“

„education 4.0“

… and more

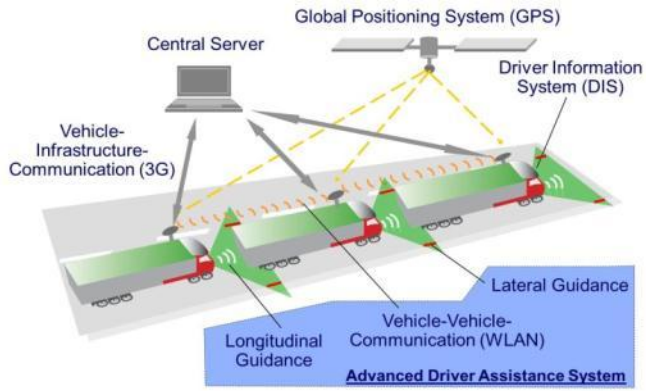
“Informatics is the new latin”…



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:
  - Car2infrastrcuture components!
  - Model of multi agent systems

→
- expected improvements: beyond safety, reduction of fuel consumption and gained road space

Connectivity…

Technological development – … to decentralized lot size 1

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

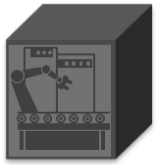
Product agitates as “super-agent”:

- Plans production and transportation steps
- Requests service from agents
- Negotiates with other products for agent-resources

outside world

transport unit

production unit



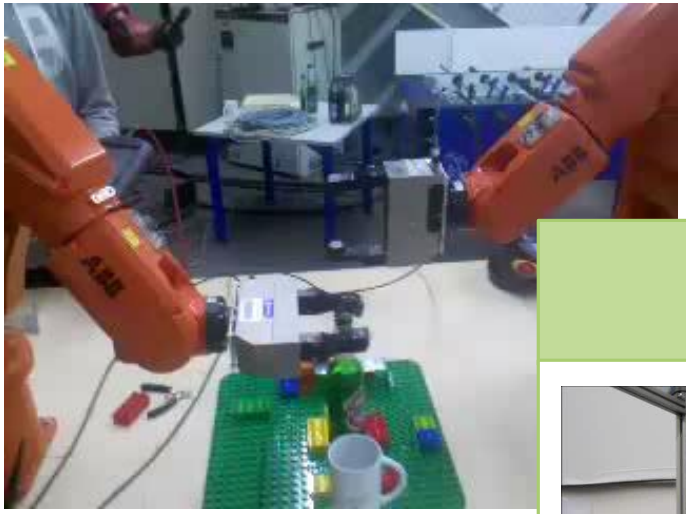
fabrication

virtual service provider

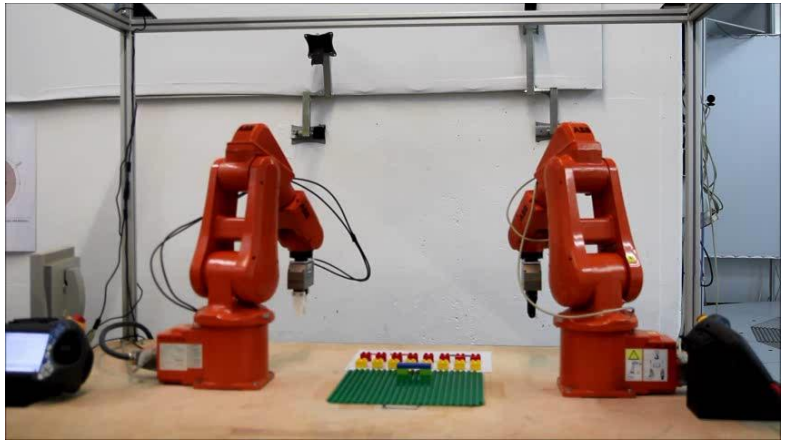
…to socio-technical assembly systems and cooperative robotics

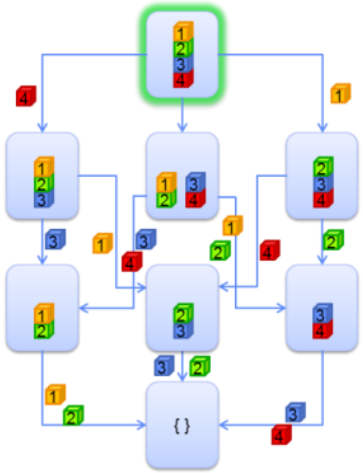
Robots are no longer locked in work-cells but cooperate with each other and/or with humans

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**

AI 4.0: Robocup Festo Logistics League / Robotinos

Mobile transportation robots from flexible routing

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

Competitions robocup:

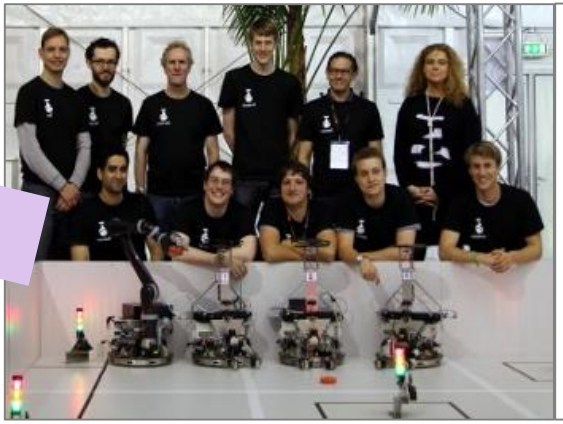
2012: 0 points in World Cup

2013: 4th in World Cup

2014: Winner of the GermanOpen

2014: Winner of the World Cup
new League High Score

http://www.carologistics.org/



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

Leading to: Interdisciplinary science and education

Natural language communication

Virtual reality

Augmented reality

Human-Maschine Interaction

Antropo-morphism

Uncanny valley

Social Robotics

Automated driving

Lightweight robots

Autonomous systems

Autonomous flying

New fields of work

Smart Logistics

Cloud logistics

Swarm robotics

Car2X

Autonomouos intralogistics

… ? …

Business Computing

Risc analysis

Data Analysics

Implications for Future Engineering Education

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”.

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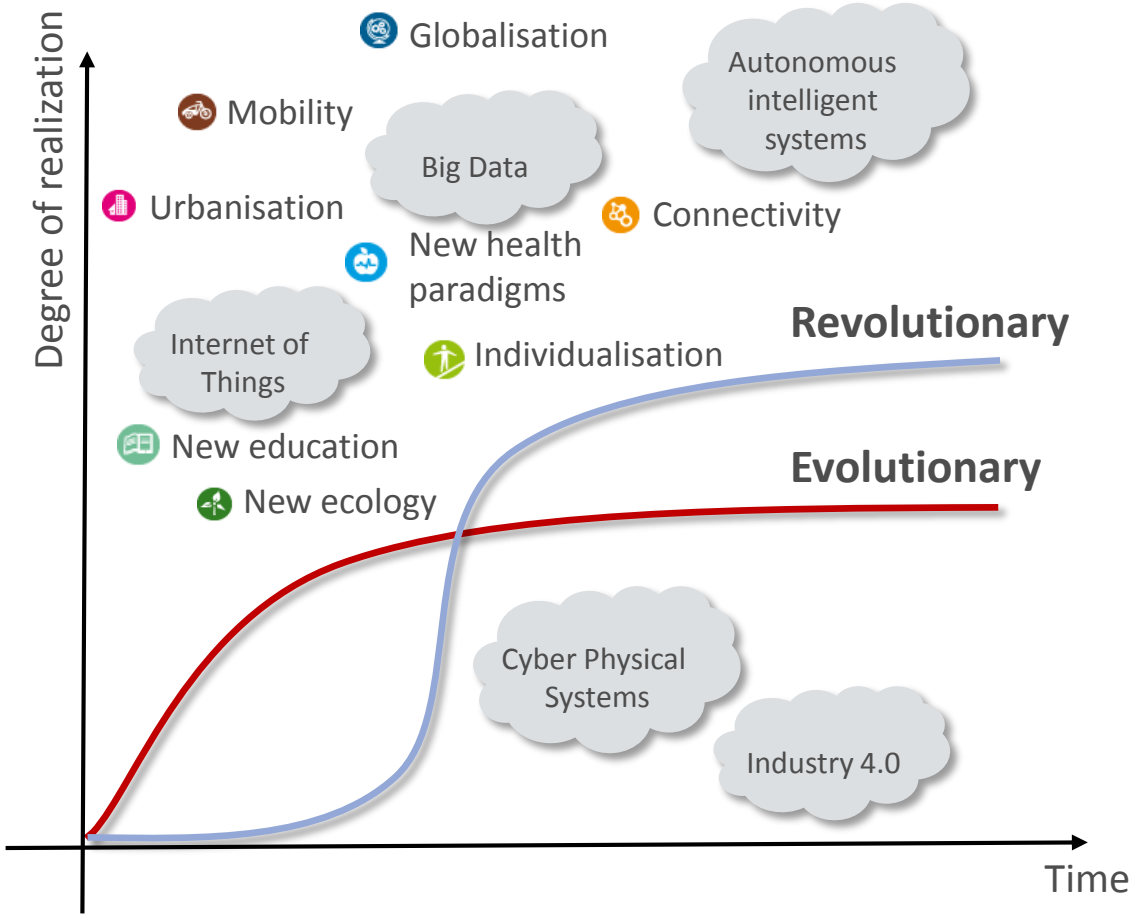
The two ways of innovation



BusinessDictionary.com
Over 20,000 Terms. Clear. Concise. Comprehensive.

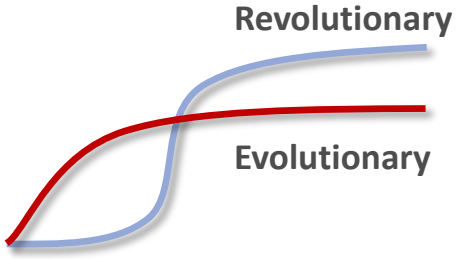
"Innovations are divided into **two categories**:

- **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

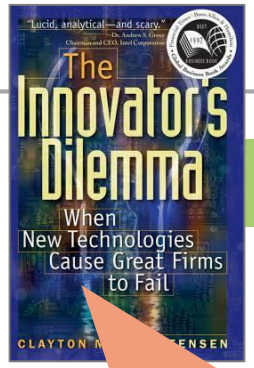


Evolutionary innovations:

- Improvement and optimization of an already existing product or process
- Changes ‚locally'
- **Mainly carried out by established players**

Revolutionary innovations:

- Something „really new"
- Characterized by categorial changes and with strong consequences for the society, ‚globally'
- **Mainly carried out by market newcomers**



By C. M. Christensen, 1997
new edition 2015

- 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**

Flashback: Schumpeter and the creative destruction

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.

↗

Theory of business cycles and development
(The theory of economic development, 1911)

- Importance of "Unternehmergeist"
- Innovation and imitation as driving forces of competition
- Political business cycle
- Theory of capitalism and socialism

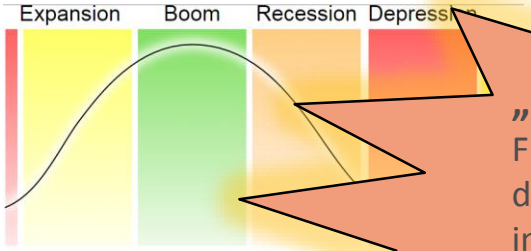
!

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, revolutional innovations

Innovation – A question of culture?!

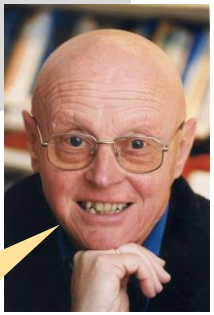
→ **Since the 1960s:**

- **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.



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

! **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.

[Wikipedia, 2015]

! **Innovation culture:**

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

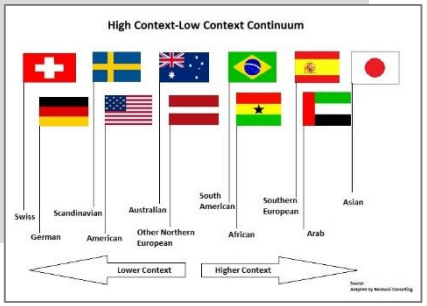
[Wikipedia, 2015]

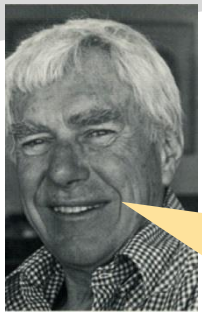
Innovation – A question of culture?!

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



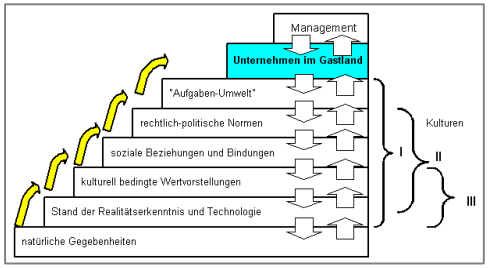


Edward T. Hall (1976):
… a culture's tendency to use high-context messages over low-context messages in routine communication.

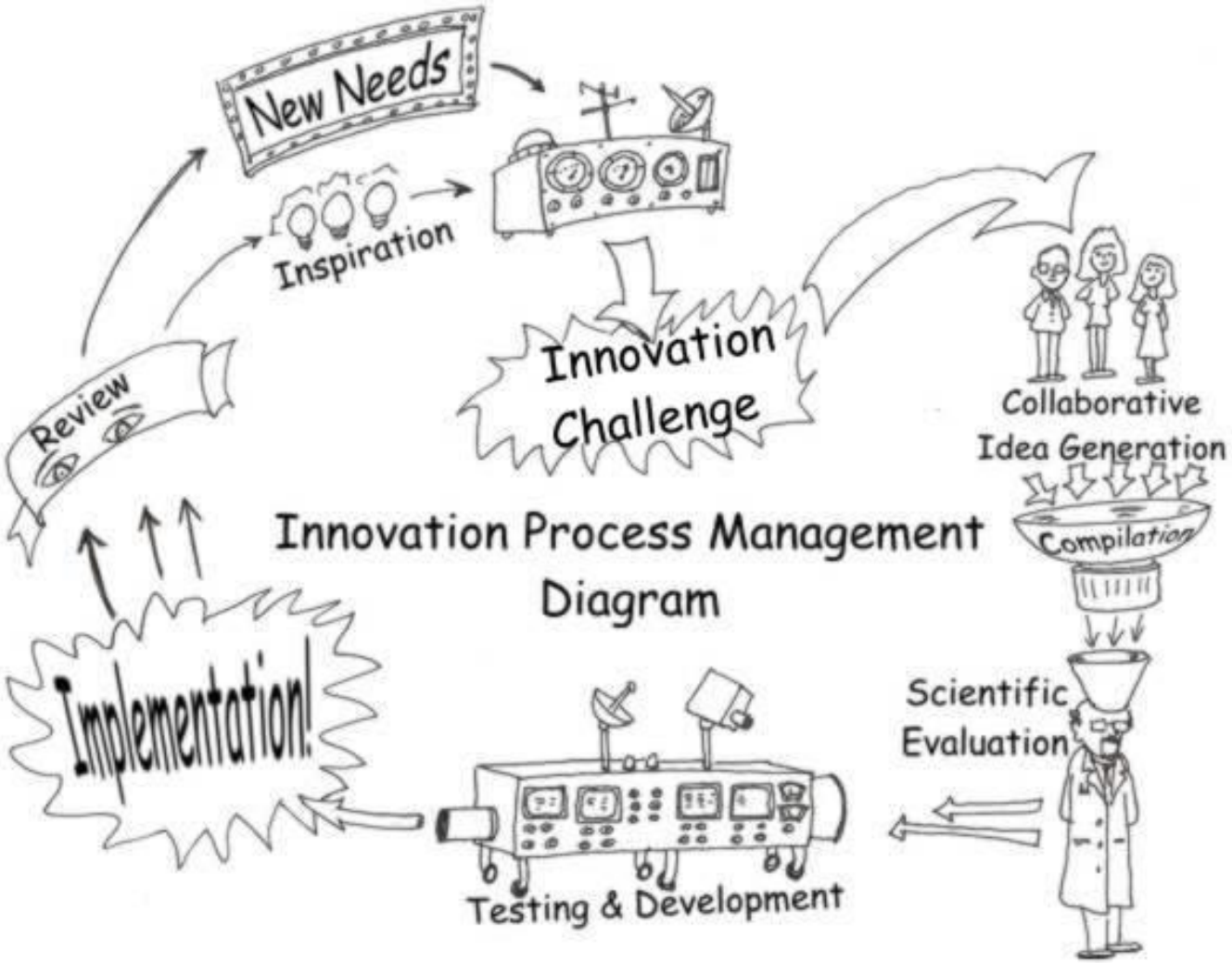
Dülfer's economical and synoptic cultural approach

- 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

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

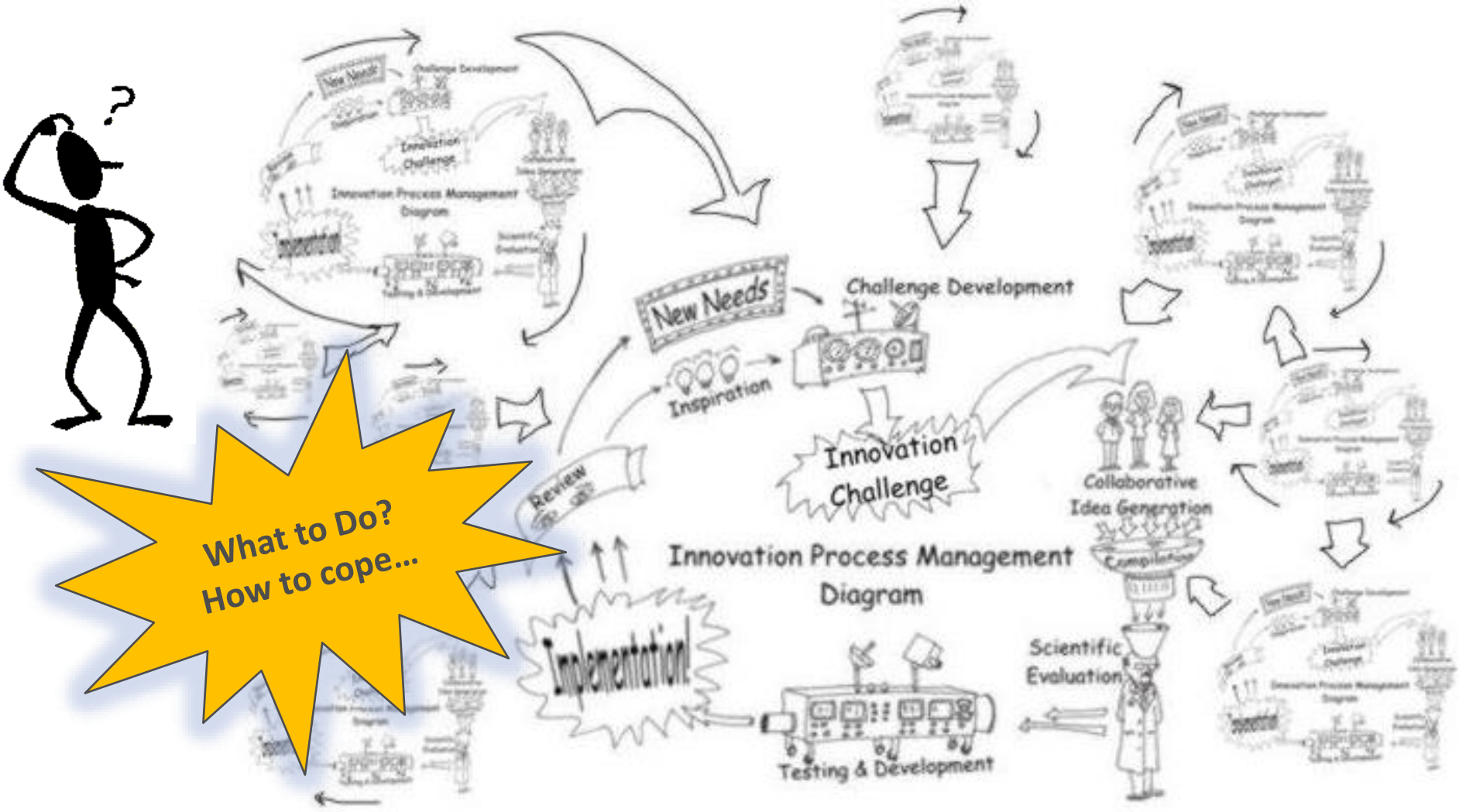


Innovation cycles become faster…



[Jeffrey Baumgartner, http://www.creativejeffrey.com/creative/ipm.php 2009]

… and faster!



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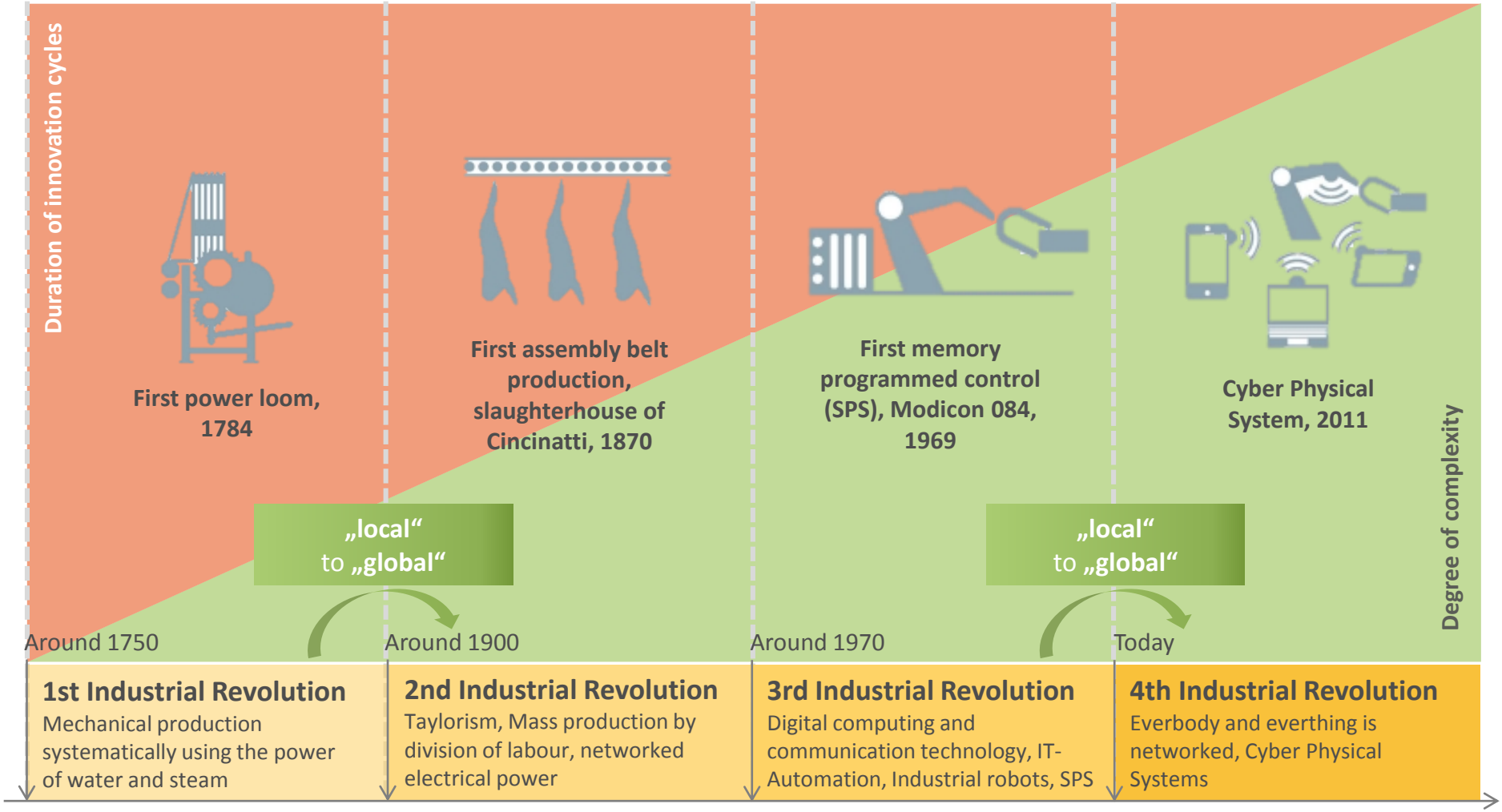
Speed and complexity of revolutional innovations

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



The vendor change around „cars“

For other dimensions of “take overs”, see keynote “Innovation 4.0”: http://www.ima-zlw-ifu.rwth-aachen.de/keynotes/LTLS_15Okt2015.pdf

Characteristics of Industrial Revolutions:
The vendor change

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

Sony announced autonomous car in 2015, based on their experience in visual sensors

SONY

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

Apple Inc.

Google: First autonomic car with street license, 2012

Google

Car specialists? – No.
- **Connectivity & data specialists.**
- **Energy & sensor specialists.**

TESLA

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

Around 1750	Around 1900	Around 1970	Today
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”

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

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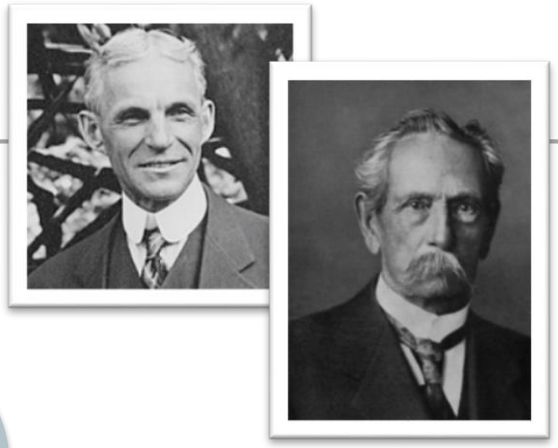
Innovation comes from fresh minds!



Capital risks

Start-Ups

Innovative Ideas

Founding a new existence

Finding out about market borders

System-oriented broad potential

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

→ **Classical Entrepreneurs needed Classical Skills…**

Entre-preneurial 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

Manage-ment 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?**

From „1 Man 1 Sign“ to the „Entrepreneur Village“

Communication technology
bandwidth and computational power

Semantic technologies
information integration

[PricewaterhouseCoopers 2008, MacCormack et al. 2007]

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 communi-cation 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

Open Innovation – success needs participation and collaboration

→ Access to crowd-sourcing, overcoming the "local search bias"…

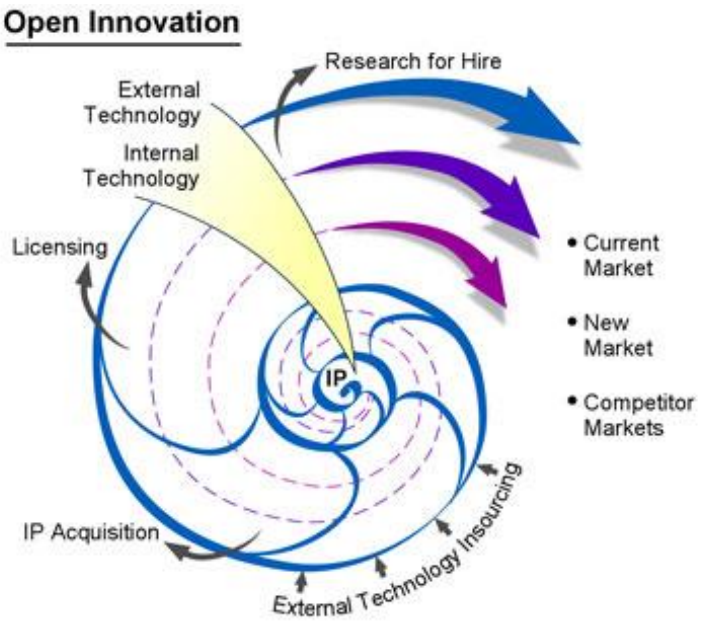
Open Innovation…

…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)

Innovation Management

Crowd Governance
Customer Co-Creation
Broadcast Search
End-User-Innovation
Lead-User

Crowd Management
Inspiration
Crowdfunding
Open Innovation



www.psicorp.com/open_innovation/index.html

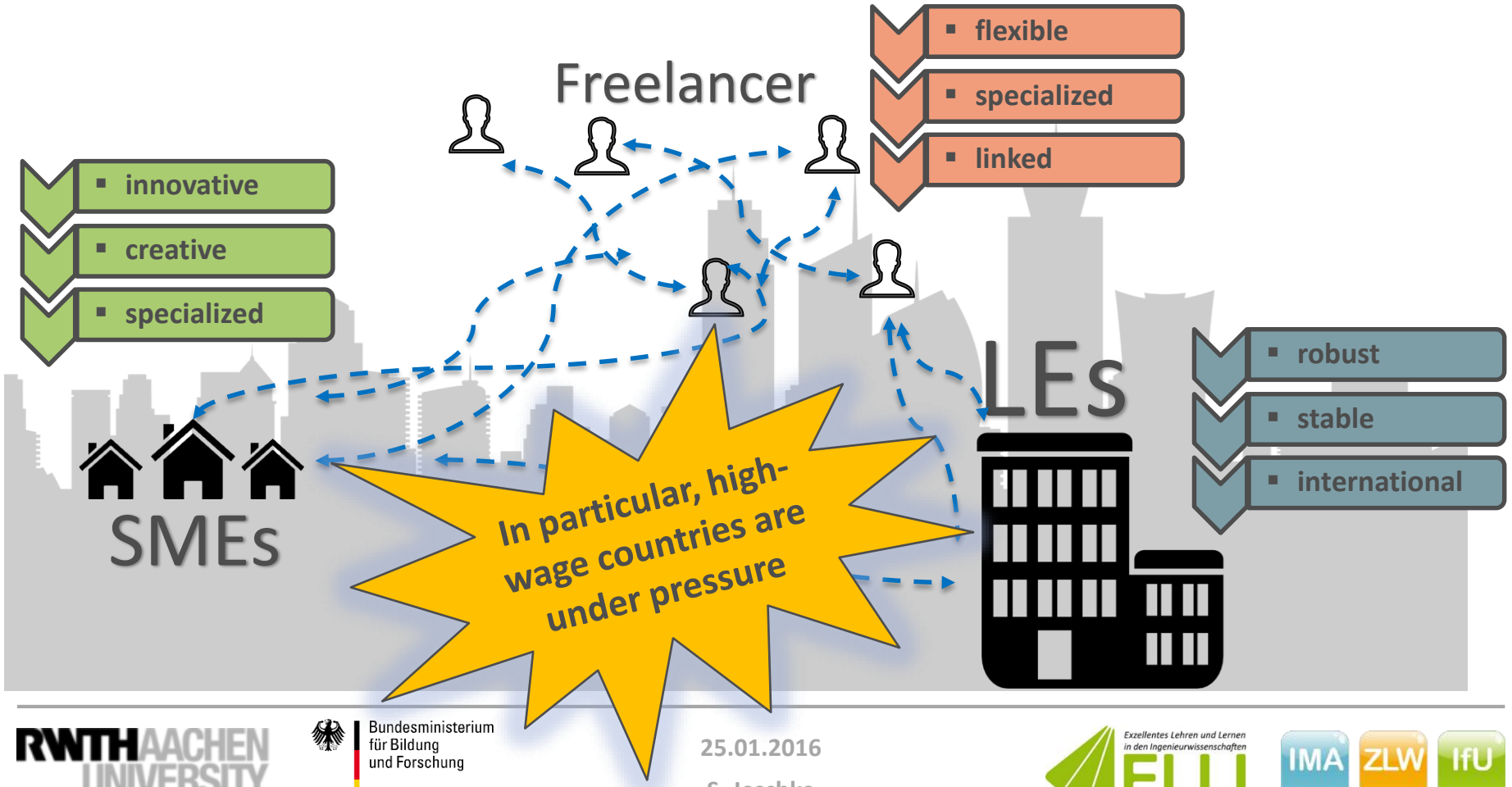
… leading to new – more social - challenges as:

- 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?
- …

Freelancers as a new form of permanent employment?

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.



New professions for a changing world

↗ **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

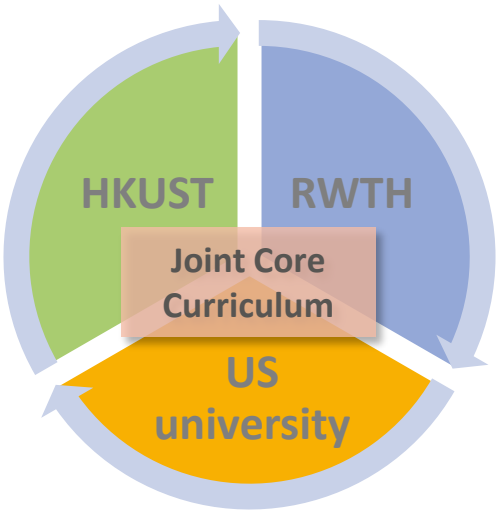
Example 1: international joint program of Entrepreneurship

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 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.

ROBOFLEX
KOE UNTERNEHMENSSIMULATION
Instructor: Prof. Ingrid Isenhardt

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

Winner's video

Implications for Future Engineering Education

IV

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”.

V

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.

VI

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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- About the connection between innovation and entrepreneurship
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- Why learning analytics will change the way we teach
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- Reshaping education: Vision or Soap-Bubble?

IV. Summary and Outlook

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

North America

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

Europe

Rest of World

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

Higher Education… the Usual Recipe ☺

Face to Face Teaching

Distribution of Learning Material

Group-/Peer-Based Learning Activities

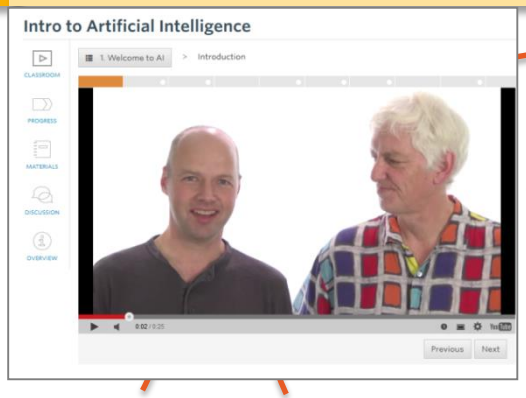
Exam & Certificates

Feedback /Peer Exchange

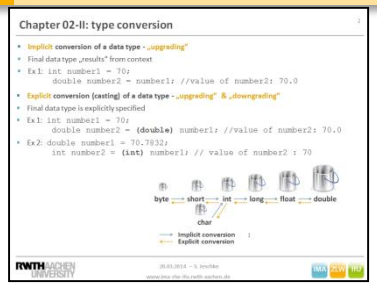
Lab Experience

Higher Education… the „New Way“

Face to Face Teaching



Online Distribution of Learning Material



Group-/Peer-Based Learning Activities

Exam & Certificates

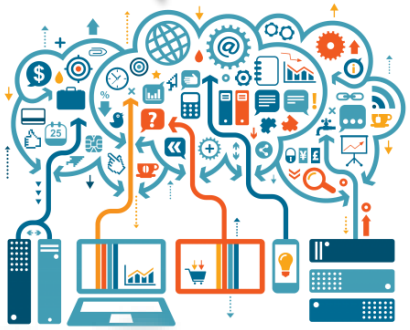
Feedback /Peer Exchange

Lab Experience

Okay, MOOCs are nice, BUT… the paragigm shift in education

Accessibility

Making education smart and individualized



Making education widely available

Log on and learn

A PC in every class!

4th industrial revolution

PCs	The Internet	Cloud and Smart Phones	Adaptive Technology
1990s	2000s	2012s	now

Let's ask Google

Google What is Big Data?

WIKIPEDIA
The Free Encyclopedia

"**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**."

Large complex data...

Heterogeneous diverse data...

IBM

"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**."

Time is ripe: new analysis

mongoDB

"**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."

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

The Big Data analysis pipeline…

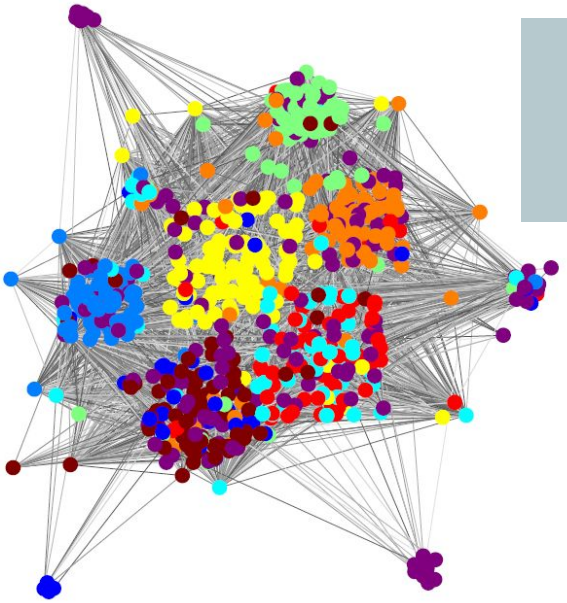
- … transfers big data (many…) into smart data (meaningful data)
- … accumulates intelligence from information fragments
- … is a pipeline of aggregating (artificial) intelligence.

Acquistion/ Recording → Extraction/ Cleaning/ Annotation → Integration/ Aggregation/ Representation → Analysis/ Modeling → Interpretation

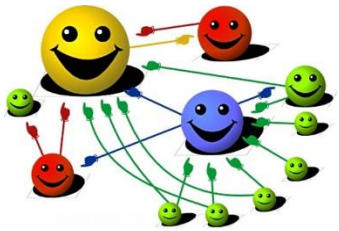
BIG DATA + SMART DATA → INTELLIGENCE/ DECISION/ INSTRUCTION

An approach towards the realization…

The pipeline for Learning Analytics in a nutshell

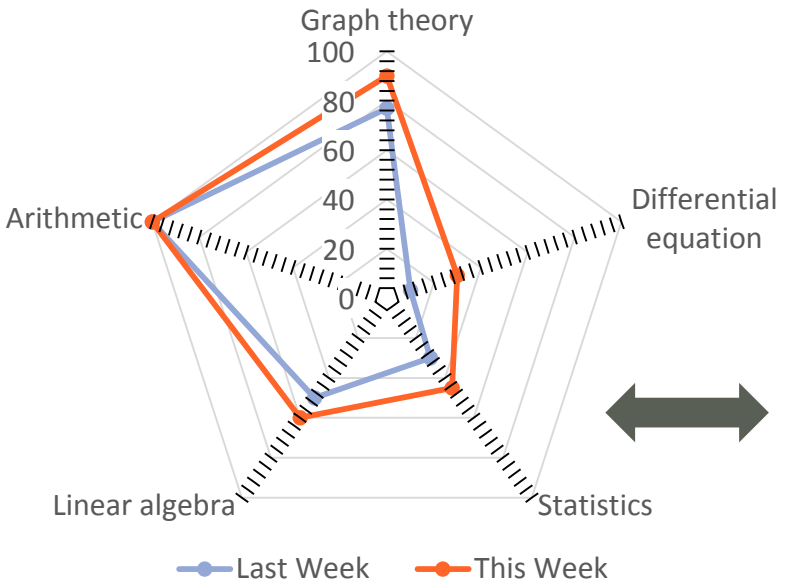


Analyse	Predict	Implement
Show data to students	Predict future developments	Develop best learning strategy
Track the individual development	Show potential problems	Adjust standards for assessments

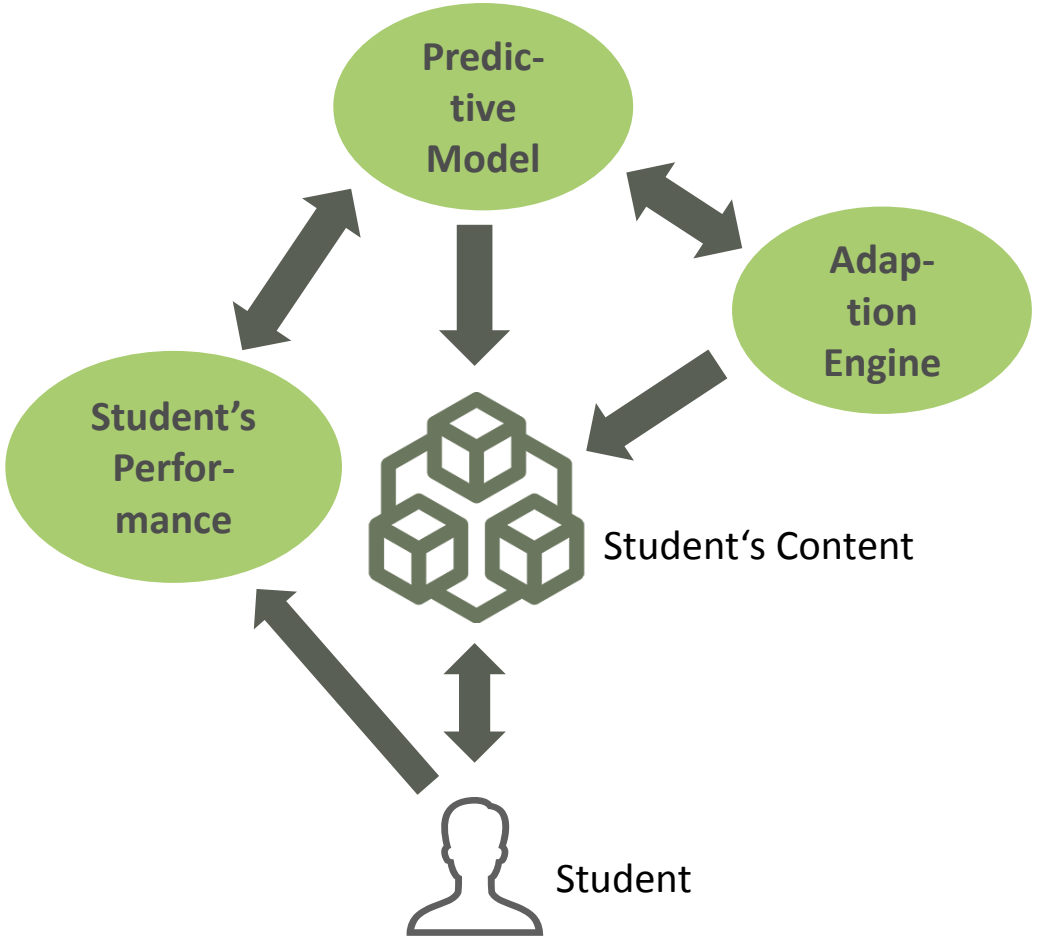


The Future: Adaptive Learning Environments

→ **Learning Analytics is the key for future adaptive learning environments**

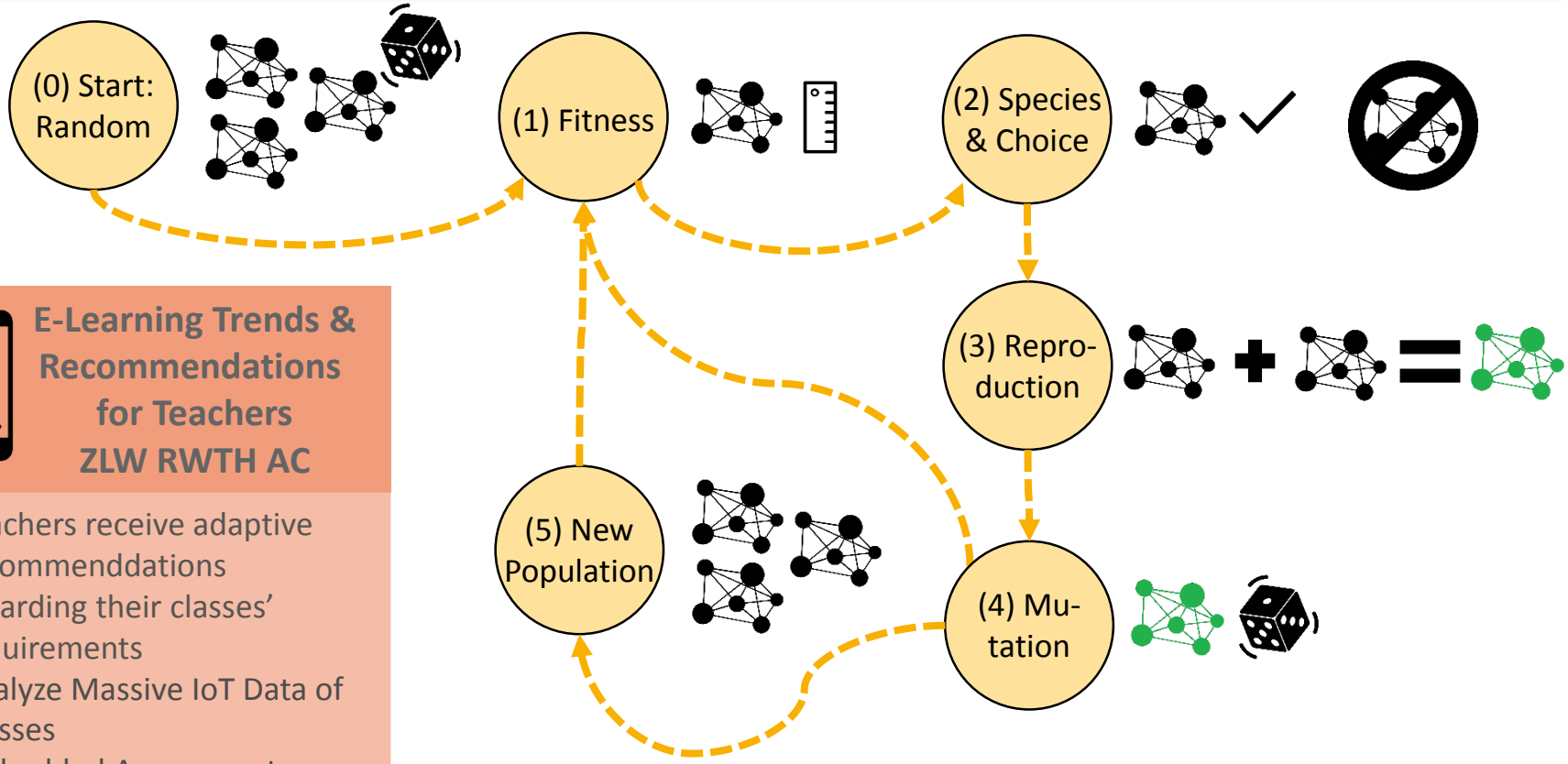


Student's performance for some topics



Neuroevolution to Evolve Artificial Intelligences

A method which imitate the evolution of biological systems in nature



E-Learning Trends & Recommendations for Teachers ZLW RWTH AC

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

Source: Stanley, K. O., Miikkulainen, R. (2002): Evolving Neural Networks through Augmenting Topologies.
Source: Russel, S., Norvig, P. (2012): Künstliche Intelligenz - Ein moderner Ansatz. ISBN: 978-3-86894-098-5

Examples: Adaptive Teaching and Learning Mathematics

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.

Ebner 2014, http://schule.learninglab.tugraz.at/

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.

First Outcomes and Results

… from the Learning-Analytics Tool LeMo

[Elkina et al., 2015 / Clow, 2015]

What is currently being measured?

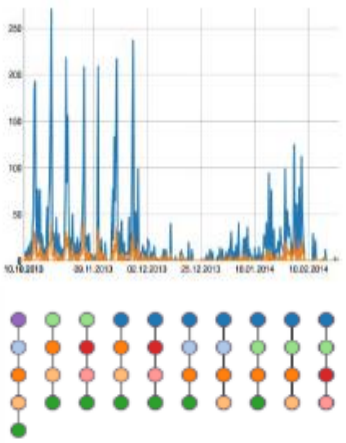
- Activity per Workday and Learning Object
- Timely order of task completion
- Learning-Path (same color = same resource)

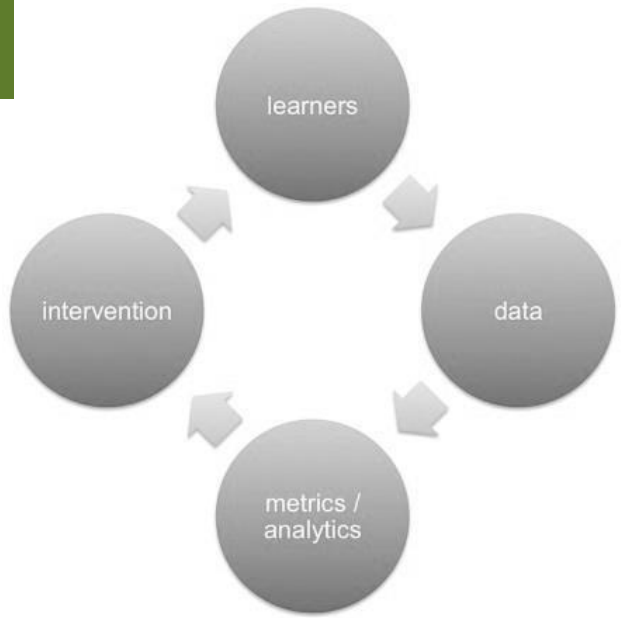
Questionnaires

- 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

Towards democratized, diverse and globalized education

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

Individual

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

Non-privileged

- All you need is a web connection
- (Higher) Education becomes affordable
- Flflexibility
- Independence from real-life teachers

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]

Changes needed for Higher Education Institutions

VII

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 loose interest.

VIII

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.

IX

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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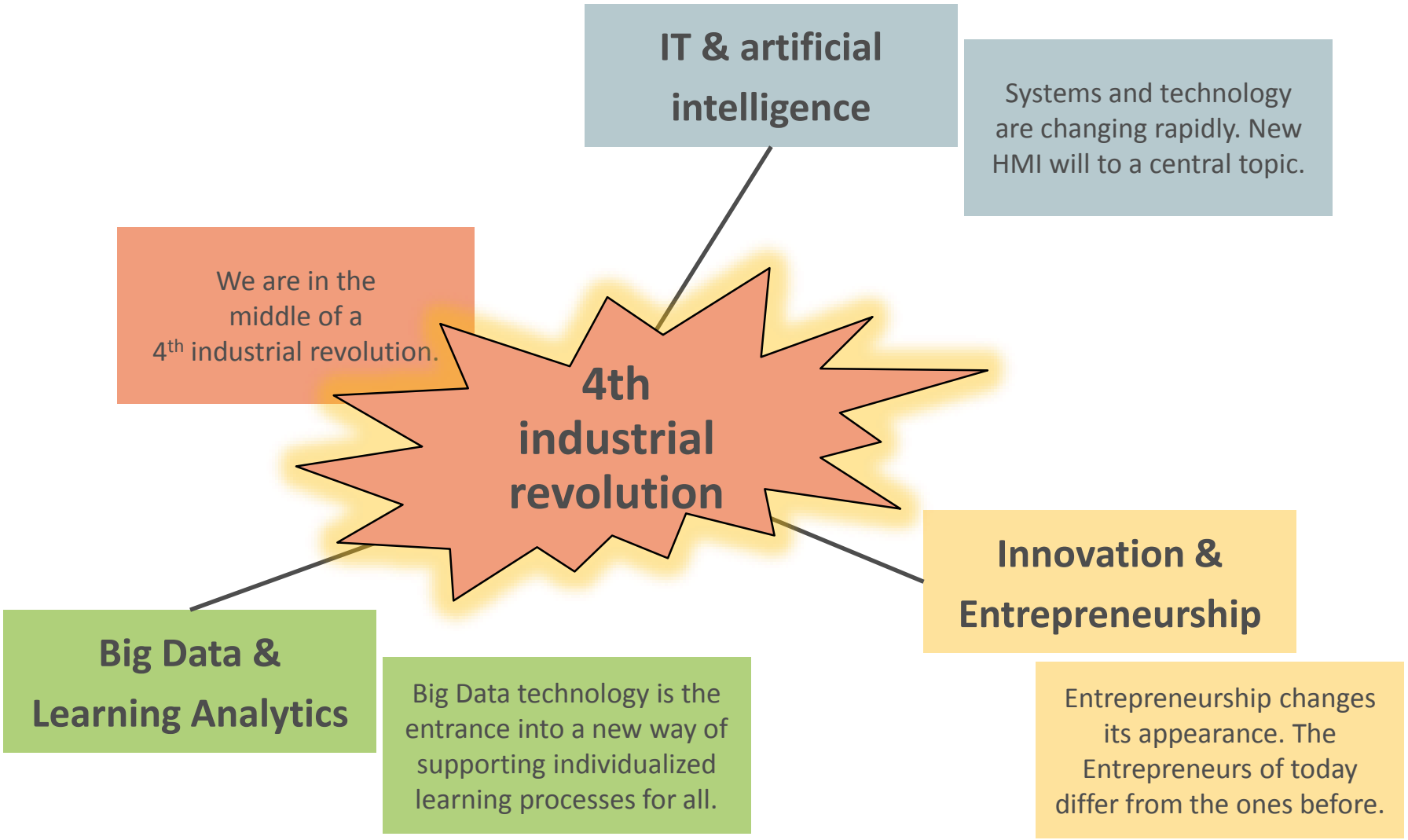
… in three steps!



Thank you!

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1994	**NASA** Ames Research Center, Moffett Field, **CA/USA**
10/1994	Fellowship „Studienstiftung des Deutschen Volkes“
1997	Diploma Physics
1997 – 2000	**Research Fellow** , TU Berlin, Institute for **Mathematics**
2000 – 2001	**Lecturer**, Georgia Institute of Technology, **GA/USA**
2001 – 2004	**Project leadership**, TU Berlin, Institute for Mathematics
04/2004	**Ph.D.** (Dr. rer. nat.), TU Berlin, in the field of **Computer Sciences**
2004	Set-up and leadership of the Multimedia-Center at the TU Berlin
2005 – 2007	**Juniorprofessor** „New Media in Mathematics & Sciences“ & Director of the **Multimedia**-center MuLF, TU Berlin
2007 – 2009	**Univ.-Professor**, Institute for IT Service Technologies (IITS) & Director of the Computer Center (RUS), Department of **Electrical Engineering**, University of **Stuttgart**
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since 03/2012	**Chairwoman VDI Aachen**
since 05/2015	**Supervisory Board of Körber AG**, Hamburg