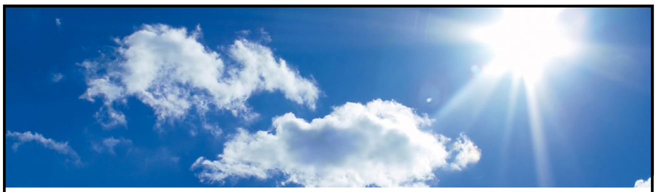


Competences in science education

the German (Bildung) and the US (curriculum) perspective

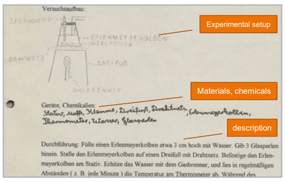
Competences in science education | Prof. Dr. Mathias Ropohl | Nov 18th 2021

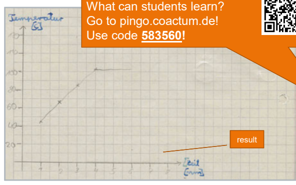
UNIVERSITÄT DUISBURG ESSEN
Open-Minded

Intro

What do you think can students learn in this situation?

A typical work sheet that students received in chemistry:





Imagine the learning situation represented by these artefacts. What can students learn? Go to pingo.coactum.de! Use code **583560**!

(Ropohl, 1994)

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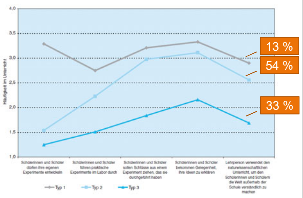
Intro

Hands on vs. minds on?

- using cook-book recipes
- doing few experiments in the sense of inquiry
- neglecting "insights" into authentic research
- spending much time for side activities
- initiating linear rather cyclical cognitive processes
- reflecting on the activities/on the cognitive process very seldom

(Duit, 2005; Prenzel et al., 2003; Seidel et al., 2004)



(PISA-Konsortium Deutschland, 2007, p. 165)

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Intro

Today's agenda

- Competences in (science) education
- *Bildung* and its relation to competences
- Educational monitoring
- US perspective on benchmarks and curricula

(visitvejle.de)

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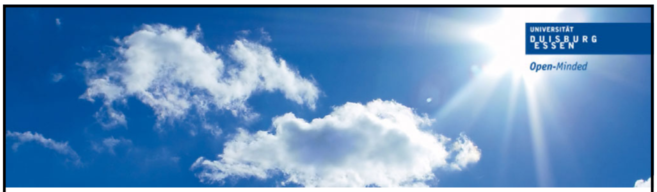

Competences

Defining educational objectives in science

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Competences in general

Perspectives on the term *competence*

1. competencies as **general cognitive abilities** and skills that enable individuals to master demanding tasks in different content domains,
2. competencies as **context-specific cognitive performance dispositions** that functionally relate to specific classes of situations and requirements (also characterized as knowledge, skills or routines),
3. competencies in the sense of the **motivational orientations** necessary for mastering demanding tasks,
4. **action competence** as an integration of the first three concepts, related to the requirements of a specific field of action such as a profession,
5. **meta-competencies** as the knowledge, strategies or motivations that facilitate both the acquisition and the application of specific competencies,
6. **key competencies** as competencies in the functional sense mentioned under 2. but relevant to a relatively broad range of situations and requirements (e.g. mother tongue or mathematical skills).

(cf. Weinert, 2001)

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Competences in general

A definition of the term *competence*

Kompetenzen sind…
„die bei Individuen verfügbaren oder durch sie erlernbaren kognitiven Fähigkeiten und Fertigkeiten, **um bestimmte Probleme zu lösen**, sowie die damit verbundenen **motivationalen, volitionalen und sozialen Bereitschaften und Fähigkeiten**, um die Problemlösung **in variablen Situationen** erfolgreich und verantwortungsvoll nutzen zu können."

(Weinert, 2001, p. 27)

(Verlagsgruppe Beltz, 2021)

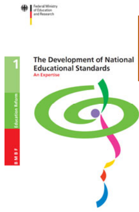
According to this definition, competence is a disposition that enables people to solve particular types of problems, that is, to deal with certain kinds of concrete situations.

Competences in general

The development of national educational standards

"In line with Weinert (2001, p. 27f.), we define competencies as the cognitive abilities and skills possessed by or able to be learned by individuals that enable them **to solve particular problems**, as well as the **motivational, volitional and social readiness and capacity** to use the solutions successfully and responsibly **in variable situations**."

(Klieme et al., 2004, p. 65)



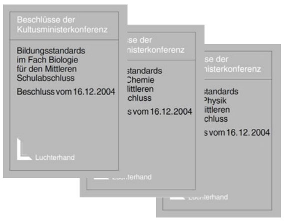
(BMBF, 2004)

This expertise initiated the "dramatic" shift from an input to an output oriented school system.

Standards in science education

The national educational standards in science education

- Competence areas — new
- Concrete competences in each competence area — new
- Performance level — more or less new
- Basic content related concepts — new
- Examples for learning tasks
- Context-based learning



(KMK, 2004, a, b, c)

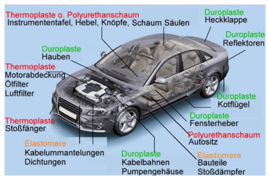
Standards in science education

The basic concepts in chemistry education

- Substance particle relationships
- Structure property relationships
- Chemical reaction
- Energetic considerations in connection with chemical reactions

(KMK, 2005)

Concept of structure-property relationships:



(Wirtschaftsgesellschaft des Kraftfahrzeuggewerbes mbH, 2008)

Standards in science education

The competence areas in science education

- Focus on process related competences
- Focus on vocational careers
- Focus on socially relevant issues

- Dependence between content and process related competence areas
- Differentiation between knowledge and competence

Competence areas in chemistry	
Content knowledge	knowing chemical phenomena, terms, and laws; assigning them to basic concepts
Scientific inquiry	using experimental and other research methods and models
Communication	Accessing and exchanging information in a factual and professional manner
Socio scientific issues	Recognizing and evaluating chemical facts in different contexts

(KMK, 2004, p. 7)

Standards in science education

The competences of the competence area *scientific inquiry*

„Die Schülerinnen und Schüler...

E 1 erkennen und entwickeln Fragestellungen, die mit Hilfe chemischer Kenntnisse und Untersuchungen […] zu beantworten sind,
E 2 planen geeignete Untersuchungen zur Überprüfung von Vermutungen und Hypothesen,
E 3 führen qualitative und einfache quantitative experimentelle und andere Untersuchungen durch und protokollieren diese,
E 4 beachten beim Experimentieren Sicherheits- und Umweltaspekte,
E 5 erheben bei Untersuchungen, insbesondere in chemischen Experimenten, relevante Daten oder recherchieren sie,
E 6 finden in erhobenen oder recherchierten Daten, Trends, Strukturen und Beziehungen, erklären diese und ziehen geeignete Schlussfolgerungen,
E 7 nutzen geeignete Modelle […] um chemische Fragestellungen zu bearbeiten,
E 8 zeigen exemplarisch Verknüpfungen zwischen gesellschaftlichen Entwicklungen und Erkenntnissen der Chemie auf."

(KMK, 2005, p. 12)

Standards in science education

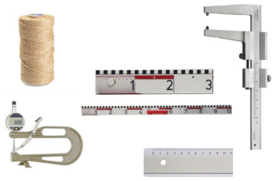
The example of *measuring*

What aspects of this activity are part of an understanding of measurement? Go to pingo.coactum.de! Use code 583560!

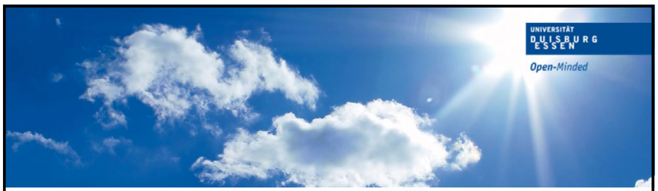
Think of a competent student in science:

- The student should measure the size of M&Ms.

- She has different options to do this.



(pictures from the web)



Bildung

Explaining the idea behind students‘ competences

Bildung in general

A description of the term *Bildung* and its different meanings

Differentiation between three dimensions of *Bildung*:

- "In the dimension of behavior, and following Baron Knigge, education means securing the expectability of behavior for others,
- in the dimension of competences, and that means: in the dimensions of the debate on PISA, it means guaranteeing a minimum of formation and cultivating the learning aptitude,
- and in the social dimension, it means the capacity to act in one's own culture. On this note, education allows self-reliant partaking in society and culture and the ability to construct one's lifetime as learning biography."

PISA 2022

(Tenorth, 2009, p. 181)

Bildung in general

The tension between the terms *Competence* and *Bildung*

"When scholars of educational science speak about the general goals of training within modern societies, they quarrel with finding a balance between [on the one hand] Bildung in the tradition of German philosophy, i.e. developing personality and allowing individuals to participate in human culture, and [on the other hand] qualification, i.e. establishing knowledge and skills that are relevant for vocational practice."

(Klieme et al. 2008, p. 6)

Bildung in general

The meaning of the term *Bildung* in the present time

"Die empirische Bildungsforschung misst Bildung hauptsächlich mit zwei Indikatoren: **dem Schulabschluss**, also dem erworbenen Zertifikat, und **mit kognitiven Kompetenzen**, also den (durch Leistungstests) gemessenen Fähigkeiten in Bereichen wie Lesen, Mathematik oder Naturwissenschaft. In beiden Fällen – Zertifikaten wie Kompetenzen – **kann Bildung als etwas verstanden werden, über das man verfügt**. Und wie man bei ökonomischen Gütern feststellen kann, dass sie ungleich verteilt sind, lässt sich auch für Bildung die gesellschaftliche Verteilung betrachten: Bildungsreich sind dann Menschen mit dem höchstmöglichen Schulabschluss, dem Abitur, bildungsarm sind Menschen ohne schulischen Abschluss. Bei den kognitiven Kompetenzen können Menschen in der untersten Kompetenzstufe – sogenannte 'funktionale Analphabeten' – als bildungsarm gelten, bildungsreich sind entsprechend Menschen in der höchsten Kompetenzstufe."

(Allmendinger, 2013, p. 6)

Bildung and science education

Bildung and the example of *Doing experiments*

scientific perspective on *Bildung*
Doing experiments as a scientific method (= a student can gain new knowledge.)

"classical" perspective on *Bildung*
Doing experiments as a material *Bildung* (= a student must know how to do experiments!)

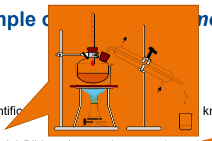
functional *Bildung*
Doing experiments as an occasion for reflection of own skills (= a student knows his potential.)

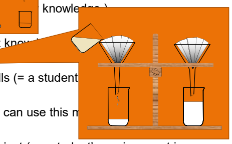
methodical *Bildung*
Doing experiments as a generalizable method (= a student can use this method in other contexts.)

categorial *Bildung*
Doing experiments as an antinomy between subject and object (= a student's environment is open for investigations and the student is ready for investigating the environment.) (Emden et al., 2019)

Bildung and science education

Bildung and the example o... ...*ments*





scientific perspective on *Bildung*

Doing experiments as a scientific... ...knowledge.)

“classical” perspective on *Bildung*

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categorial *Bildung*

Doing experiments as an antinomy between subject and object (= a student’s environment is open for investigations and the student is ready for investigating the environment.) (Emden et al., 2019)

Bildung and science education

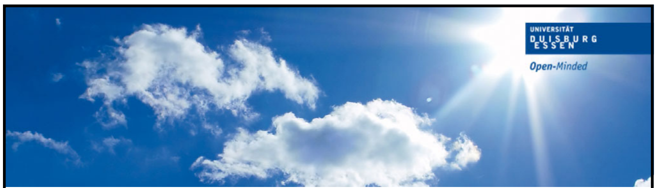
The example of *controlling variabels*

Investigating the thermal conductivity of metals:

- How do the metals copper and iron differ in their thermal conductivity?
- Copper has a higher conductivity than iron.

What is the educational value of this learning opportunity?
Go to pingo.coactum.de!
Use code 583560!

(Scheuermann & Ropohl, 2017, p. 20)



Educational monitoring

Measuring competences

Educational monitoring

Educational monitoring in Germany

- Participation in international large-scale assessments
- Monitoring and implementation of educational standards for primary and lower secondary education as well as the general qualification for university entrance
- Quality assurance procedures at the individual schools level
- Educational reporting

(KMK, 2015)

(Autorengruppe Bildungsberichterstattung, 2020)

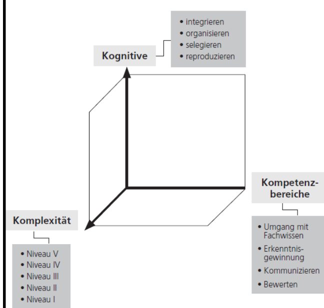
Educational monitoring

When are students’ competences monitored?

Jahr	Testung					
	PIRLS	TIMSS	PISA	IQB-Ländervergleiche		
	Grundschule		Sek. I	Grundschule	Sekundarstufe I	
					Mathe, Nat.	Deu, Engl/Fr
2009			●			●
2010						
2011	●	●		●		
2012			●		●	
2013						
2014						
2015		●	●			●
2016	●			●		
2017						
2018			●		●	
2019		●				
2020						
2021	●		●	●		●

(KMK, 2015, p. 18)

Overview of test cycles for the educational monitoring



Educational monitoring

Competence models

Complexity
Cognitive processes
Competence areas

(Kauertz et al., 2010, S. 145)

Educational monitoring

How are students' competences measured?

Im Chemieunterricht wird in einem Versuch Salzsäure zu Zink gegeben.

Es soll die Frage geklärt werden, ob die Temperatur der Ausgangsstoffe einen Einfluss auf die Reaktionsgeschwindigkeit hat.

Welche der folgenden Kombinationen V_1-V_4 ist geeignet, um diese Frage zu beantworten?

Kreuze die richtige Kombination an.

	Versuch	Masse des Zinkstückes	Volumen an Salzsäurelösung	Temperatur der Salzsäurelösung
☐	V_1	5 g	10 mL	30 °C
		5 g	10 mL	50 °C
☐	V_2	5 g	10 mL	30 °C
		10 g	5 mL	50 °C
☐	V_3	10 g	10 mL	30 °C
		10 g	10 mL	30 °C
☐	V_4	10 g	10 mL	30 °C
		5 g	10 mL	50 °C

(IQB, 2018)

exemplary test task measuring 9th grade students' competence in the competence area *scientific inquiry*

What percentage of students solved the item correctly? Go to pingo.coactum.de! Use code **583560!**

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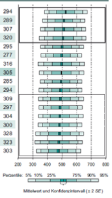
Educational monitoring

How competent are today's students?

Land	M	(SE)	SD	(SE)	Perzentile 5	10	25	75	90	95	95-5
Sachsen	**525**	(2.5)	90	(2.0)	379	410	462	587	641	673	294
Thüringen	**512**	(3.3)	**88**	(2.3)	367	400	451	573	625	656	289
Bayern	**512**	(3.4)	94	(2.4)	353	384	446	580	632	660	307
Sachsen-Anhalt	**506**	(3.1)	98	(2.7)	344	381	438	577	635	664	320
Baden-Württemberg	500	(3.0)	91	(2.3)	353	384	435	564	617	648	295
Brandenburg	497	(2.9)	**84**	(2.0)	356	389	441	557	606	633	277
Rheinland-Pfalz	497	(3.4)	96	(2.5)	336	375	433	564	620	652	316
Deutschland	496	(1.3)	94	(0.9)	344	375	430	563	618	649	305
Mecklenburg-Vorpommern	493	(3.2)	**87**	(2.1)	350	380	433	554	606	635	285
Niedersachsen	491	(4.5)	91	(2.7)	342	373	430	554	608	636	294
Nordrhein-Westfalen	**488**	(3.6)	94	(2.7)	338	369	421	555	613	647	309
Saarland	**486**	(3.9)	91	(3.0)	341	371	424	547	606	638	297
Schleswig-Holstein	**485**	(3.2)	93	(2.1)	339	369	419	551	610	643	304
Hessen	**483**	(2.8)	92	(2.3)	335	365	417	547	603	635	300
Berlin	**482**	(3.5)	**101**	(2.2)	320	351	407	556	617	648	328
Hamburg	**478**	(3.1)	**99**	(2.3)	315	351	410	548	608	638	323
Bremen	**474**	(4.4)	93	(3.1)	324	356	408	540	594	627	303



☐ Länder liegen signifikant ($p < .05$) über dem deutschen Mittelwert.
☐ Länder liegen signifikant ($p < .05$) unter dem deutschen Mittelwert.

(Stanat et al., 2019, p. 217)

Mean value, spread of values, percentiles and percentile bands of 9th grade students' competences in chemistry for the competence area **scientific inquiry**

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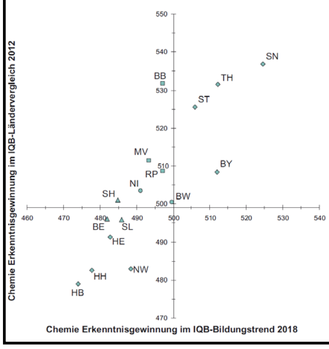

Educational monitoring

How competent are today's students compared to the previous educational monitoring?

Mean scores for each state in the competence area scientific inquiry in chemistry in the IQB-Ländervergleich 2012 and the IQB-Bildungstrend 2018

(Stanat et al., 2019, p. 228)

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Educational monitoring

Summary of the so called *Bildungstrend*

- The distribution of ninth graders across the proficiency levels for the science subjects indicates
  - substantial differences between the states,
  - broad stability between 2012 and 2018 for Germany as a whole,
  - and isolated favorable and several unfavorable developments within the states.
- The percentage of students who achieve at least the regular standard for the qualification after lower secondary school level varies from 56 percent (content knowledge in chemistry) to nearly 77 percent (scientific inquiry in physics).

(Stanat et al., 2019)

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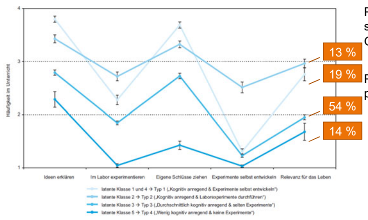
Educational monitoring

Did the reform change practice?



(Schiepe-Tiska et al., 2016, p. 158)

Profiles of latent classes for 15 year-old students' teaching style perceptions in Germany

Percentage frequencies of instructional patterns overall

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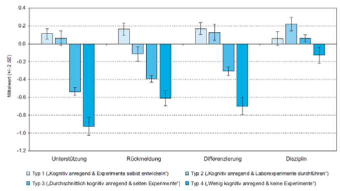
Educational monitoring

Did the reform change practice?



(Schiepe-Tiska et al., 2016, p. 162)

Comparison of instructional patterns with respect to general characteristics of the quality of teaching

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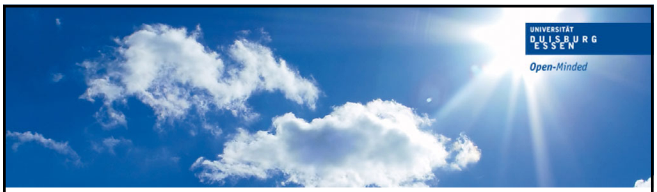


Benchmarks and three dimensional learning in science

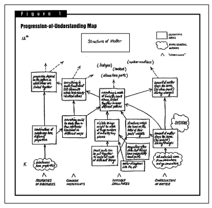
Looking at the US perspective

The US perspective

Benchmarks in science education

- Benchmarks are a basis for curriculum development.
- Benchmarks relate to scientific literacy.
- Benchmarks refer to grades (k-2, 3-5, 6-8, 9-12).
- Benchmarks are sequenced within a grade level.
- Benchmarks progress from one grade level to the next.

(cf. Ahlgren, 1993, p. 49)

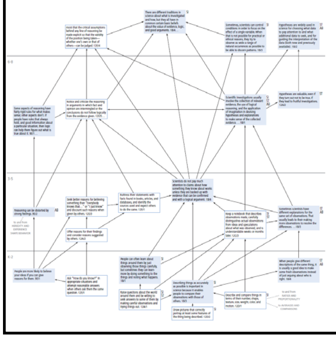


(Ahlgren, 1993, p. 47)

The US perspective

Students‘ conceptions of evidence and reasoning in inquiry

- Middle-school students tend to invoke personal experiences as evidence to justify a particular hypothesis. They seem to think of evidence as selected from what is already known or from personal experience or secondhand sources, not as information produced by experiment.
  (Roseberry et al., 1992)
- When asked to use evidence to judge a theory, students of all ages may make only theory-based responses with no reference made to the presented evidence. Sometimes this appears to be because the available evidence conflicts with the students' beliefs.
  (Kuhn et al., 1988)
- Most high-school students will accept arguments based on inadequate sample size, accept causality from contiguous events, and accept conclusions based on statistically insignificant differences.
  (Jungwirth & Dreyfus, 1990, 1992; Jungwirth, 1987)



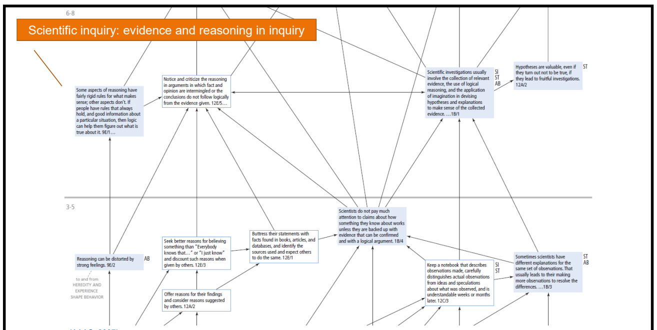
The US perspective

Conceptual strand maps as a representation of benchmarks

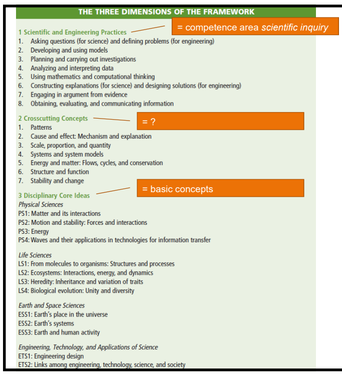
Scientific inquiry is built on…

- the interaction of evidence and logical reasoning,
- the importance of careful observation, the role of observations in supporting a line of reasoning,
- and the value of reasoning in suggesting new observations.

(AAAS, 2007)



(AAAS, 2007)



THE THREE DIMENSIONS OF THE FRAMEWORK

1 Scientific and Engineering Practices — = competence area *scientific inquiry*
1. Asking questions (for science) and defining problems (for engineering)
2. Developing and using models
3. Planning and carrying out investigations
4. Analyzing and interpreting data
5. Using mathematics and computational thinking
6. Constructing explanations (for science) and designing solutions (for engineering)
7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating information

2 Crosscutting Concepts — = ?
1. Patterns
2. Cause and effect: Mechanism and explanation
3. Scale, proportion, and quantity
4. Systems and system models
5. Energy and matter: Flows, cycles, and conservation
6. Structure and function
7. Stability and change

3 Disciplinary Core Ideas — = basic concepts

Physical Sciences
PS1: Matter and its interactions
PS2: Motion and stability: Forces and interactions
PS3: Energy
PS4: Waves and their applications in technologies for information transfer

Life Sciences
LS1: From molecules to organisms: Structures and processes
LS2: Ecosystems: Interactions, energy, and dynamics
LS3: Heredity: Inheritance and variation of traits
LS4: Biological evolution: Unity and diversity

Earth and Space Sciences
ESS1: Earth's place in the universe
ESS2: Earth's systems
ESS3: Earth and human activity

Engineering, Technology, and Applications of Science
ETS1: Engineering design
ETS2: Links among engineering, technology, science, and society

The US perspective

Three dimensional learning in science education

- Dimension 1 describes scientific and engineering practices.
- Dimension 2 describes crosscutting concepts—that is, those having applicability across science disciplines.
- Dimension 3 describes core ideas in the science disciplines and of the relationships among science, engineering, and technology.

(NRC, 2012, p. 29)

(NRC, 2012, p. 3)

The US perspective

Practices: Planning and carrying out investigations

By grade 12, students should be able to

1. Formulate a question that can be investigated within the scope of the classroom, school laboratory, or field with available resources and, when appropriate, frame a hypothesis (that is, a possible explanation that predicts a particular and stable outcome) based on a model or theory.
2. Decide what data are to be gathered, what tools are needed to do the gathering, and how measurements will be recorded.
3. Decide how much data are needed to produce reliable measurements and consider any limitations on the precision of the data.
4. Plan experimental or field-research procedures, identifying relevant independent and dependent variables and, when appropriate, the need for controls.
5. Consider possible confounding variables or effects and ensure that the investigation's design has controlled for them.

(NRC, 2012, p. 60)

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The US perspective

Core Ideas: Matter and its interaction

- PS1.A: Structure and Properties of Matter
  - How do particles combine to form the variety of matter one observes?
- PS1.B: Chemical Reactions
  - How do substances combine or change (react) to make new substances? How does one characterize and explain these reactions and make predictions about them?
- PS1.C: Nuclear Processes
  - What forces hold nuclei together and mediate nuclear processes?

End of grade 12
Each atom has a charged substructure consisting of a nucleus, which is made of protons and neutrons, surrounded by electrons. …

End of grade 8
All substances are made from some 100 different types of atoms, which combine with one another in various ways. …

End of grade 5
Matter of any type can be subdivided into particles that are too small to see, but even then the matter still exists and can be detected by other means…

End of grade 2
Different kinds of matter exist (e.g., wood, metal, water), and many of them can be either solid or liquid, depending on temperature…

(NRC, 2012, p. 108-109)

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The US perspective

Crosscutting concepts: patterns

- Patterns
- Cause and effect: Mechanism and explanation
- Scale, proportion, and quantity
- Systems and system models
- Energy and matter
- Structure and function
- Stability and change

(NRC, 2012)

"Observed patterns of forms and events guide organization and classification, and they prompt questions about relationships and the factors that influence them."

(NRC, 2012, p. 84; Spiegel, 2012)

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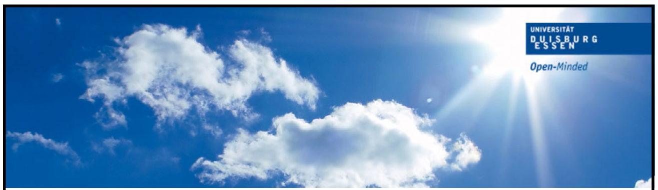

Some concluding thoughts

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Concluding thoughts

Theses

- Educational goals are set normatively.
- Education is made measurable by operationalizing affordances by items.
- Education focuses strongly on linking content or specific contexts and competencies.
- Education focuses strongly on subject-specific learning.
- Education focuses strongly on social participation and professional careers.

Hands on
AND
Minds on!

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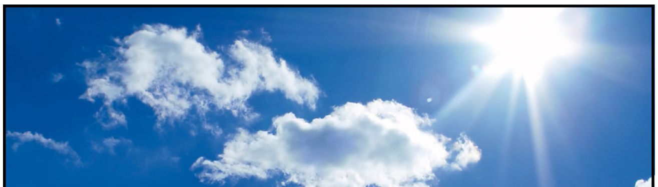

Tak!

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