Defining and Assessment of Cognitive Outcomes of Inquiry-Based Science Education
Outline

• Problems of science education and the need for improvement
  – PISA 2012 science results
  – Problem solving in PISA 2012
• Theoretical resources for understanding, representing and solving the problems
• What to assess: Framework development in SAILS
• Challenges, problems and perspectives in implementing assessment
Problems of science education:
Results of PISA 2012
PISA 2012: Mean achievements in science
PISA 2012: Proportion of students achieving at level 6 in Science (%)
Although in many countries the traditional goals of science education are not met yet, new goals appeared: to develop the 21\textsuperscript{st} century skills, e.g. creativity, critical thinking and problem solving.
PISA 2012: Achievements in Problem Solving
Relative performance in Problem Solving

Students’ performance in problem solving is higher than their expected performance.

Students’ performance in problem solving is lower than their expected performance.
Does the same solution work for each country?

Our Education System
Some conclusions of the PISA results

• There are large differences between the SAILS partner countries
  – in the mean achievements
  – in the quality of students’ knowledge

• High achievements in the main domains do not guarantee good problem solving

• A deeper understanding of the organization of students’ knowledge is needed

• A more sophisticated assessment framework is required
How can Inquiry-Based Science Education contribute to the improvement of science achievements?

Can IBSE improve Problem Solving skills?
In the first phase, EU projects focused on developing IBSE methods and training of teachers to use them.
“Experience alone does not create knowledge.”

Kurt Lewin
EU FP7 projects on science education

CarboSchools+  European network of regional projects for school partnerships on climate change research
CoReflect  Digital support for Inquiry, Collaboration, and Reflection on Socio-Scientific Debates
Mind the Gap  Learning, Teaching, Research and Policy in Inquiry-Based Science Education
HIPST  History and Philosophy in Science Teaching
EUCUNET  European Children’s Universities Network
YOSCIWEB  Young people and the images of science on websites
MOTIVATION  Promoting positive images of SET in young people
S-TEAM  Science-Teacher Education Advanced Methods
ESTABLISH  European Science and Technology in Action Building Links with Industry, Schools and Home
FIBONACCI  Large scale dissemination of inquiry based science and mathematics education
PRIMAS  Promoting Inquiry in Mathematics and Science Education
KIDSINNSCIENCE  Innovation in Science Education - Turning Kids on to Science
SED  Science Education for Diversity
TRACES  Transformative Research Activities. Cultural diversities and Education in Science
PROFILES  Professional Reflection-Oriented Focus on Inquiry-based Learning and Education through Science
Pathway  The Pathway to Inquiry Based Science Teaching
INQUIRE  Inquiry-based teacher training for a sustainable future
Pri-Sci-Net  Networking Primary Science Educators as a means to provide training and professional development in Inquiry Based Teaching
SECURE  Science Education Curriculum Research
ECB European  Coordinating Body in Maths, Science and Technology Education
“If you can not measure it, you can not improve it.”

Kelvin
Recent projects deal with assessment as well.

For this new approach, we need new knowledge.
“There is nothing so practical as a good theory.”

Kurt Lewin

Maybe a set of good theories is even more practical…
Theories on what to assess and how to assess

• What to assess?
  – theories of cognition
  – cognitive development
  – learning and instruction
  – curriculum development
  – standards and standard setting

• How to assess?
  – theories of educational and psychological assessment
  – classical test theory
  – modern (probabilistic) test theories
A typical misunderstanding of the role of the indicators

An analogy

Measuring and increasing room temperature
A low-cost solution
“Teaching to a test is easy. Teaching for life is hard.”
What do we really mean by increasing students’ achievements?
... increasing the quantity of students’ knowledge or

... improving the quality of students’ knowledge
For measuring students’ knowledge we need a more sophisticated instrument than this one.
A framework for representing problems of the quality of students’ knowledge
Dimensions of Knowledge

INTERNAL REFERENCE
Basic skills – general abilities continuum
Cognitive skills, competencies etc.

EXTERNAL (SOCIAL) REFERENCE
General literacy: social, cultural, ”lay”, “civic” dimension.
PISA reading literacy, mathematical literacy, scientific literacy.
Technical literacy, musical literacy, ICT literacy etc.

EXTERNAL (PROFESSIONAL) REFERENCE
Expertise (disciplinary/professional dimension)
Expert knowledge, professional knowledge
BASIC SKILLS – GENERAL ABILITIES

Psychological determination

Cultural determination

DISCIPLINARY DETERMINATION

Disciplinary determination

CONTENT KNOWLEDGE – EXPERTISE

1st and 2nd IEA Science and Mathematics Study

GENERAL LITERACY

PISA mathematical and scientific literacy

PISA 2012 Problem Solving
How PISA results can be improved?

Three different approaches may be considered
The worst option: direct teaching
The most trivial but worst option

BASIC SKILLS – GENERAL ABILITIES

Psychological determination

Disciplinary determination

CONTENT KNOWLEDGE – EXPERTISE

„Teaching for testing”

GENERAL LITERACY

Cultural determination
Better option: low-road transfer
Better option: low-road transfer

BASIC SKILLS – GENERAL ABILITIES

Psychological determination

Disciplinary determination

CONTENT KNOWLEDGE – EXPERTISE

Enriching science teaching with practical exercises

GENERAL LITERACY

Cultural determination

„Teaching for transfer”
The best option:
high-road transfer
- improving thinking
- improving understanding
The best option

BASIC SKILLS – GENERAL ABILITIES

Psychological determination

Cultural determination

Disciplinary determination

CONTENT KNOWLEDGE – EXPERTISE

Enriching teaching with thinking exercises

„Teaching for understanding”
The SAILS project has received funding from the European Union’s Seventh Framework Programme [2012-2015]
Framework development in SAILS
How an assessment framework looks like?

**PISA**
- application (literacy)

**TIMSS**
- content
- reasoning
- application

**Diagnostic**
- content
- reasoning
- application
Framework development for SAILS

- Inquiries (content, process, skills)
- Disciplinary content knowledge
  - Big ideas
  - Conceptual development (conceptual change, misconceptions)
  - Learning progression
- Application of scientific knowledge (scientific literacy)
  - Applied areas
  - Application through transfer
- Reasoning
  - Operational reasoning
  - Higher order thinking skills
  - Scientific reasoning
Inquiry skills

- Wenning:
  - Identify a problem to be investigated
  - Formulate a hypothesis
  - Design experimental procedures to test the prediction
  - Conduct a scientific experiment; collect meaningful data, organize, and analyze data accurately and precisely
  - Apply numerical and statistical methods to numerical data to reach and support conclusions
  - Using available technology, report, display, and defend the results of an investigation to audiences that might include professionals and technical experts

- Fradd:
  - Questioning
  - Planning
  - Implementing
  - Concluding
  - Reporting
  - Applying
Developing learning units

- A structure in which different examples can be documented
  - Understanding of Inquiry
  - Unit Structure
    - Section 1: Topic
    - Section 2: Content
    - Section 3: Inquiry skills
    - Section 4: Suggested Learning Sequence
    - Section 5: Assessment opportunities
A hard issue:
Improving cognitive abilities
Cognitive abilities often mentioned in the context of IBSE

- intelligence
- creativity
- critical thinking
- scientific reasoning
- problem solving
  - PISA 2012: dynamic problem solving
  - PISA 2015: collaborative problem solving
Reasoning skills relevant for mastering, organization and application of scientific knowledge

- control of variables
- organization, seriation, class inclusion, classification, multiple classification, set operations
- combinatorial reasoning, operation of binary logic
- probabilistic reasoning, risk estimation, correlational reasoning
- relations, relational reasoning
- ratio, proportional reasoning
- measurement, product of measures
- analogical reasoning, inductive reasoning
- causality
- hypothesis generation and hypothesis testing
Cognitive development and science education

Cognitive Acceleration through Science Education (CASE)

Philip Adey, Michael Shayer and Carolyn Yates: 
Thinking Science 
(1989)
Broader effects of CASE

Michael Shayer and Philip Adey:

Learning Intelligence
Cognitive Acceleration across the Curriculum from 5 to 15 Years

(2002)
Lasting effects of CASE

Philip Adey and Michael Shayer:
Really Rising Standards
Cognitive Intervention and
Academic Achievement
(1994)
Challenges in implementing assessment in SAILS
Bridging the gap between “21st century skills” and IBSE

• Strengths of “traditional” science education
  – expertise, expert knowledge (immediately applicable in the given contexts)
  – content related skills (mechanical routines)
  – domain specific problem solving

• Challenges in implementing IBSE
  – it cannot be reduced for teaching a few inquiry skills
  – it cannot be done by using old teaching routines
Bridging the gap between formative classroom assessment and assessing more general, lasting outcomes of inquiry learning

- Formative assessment deals with small pieces of knowledge and skills, but understanding and transfer can be assessed only in a broader context.
- Formative classroom assessment provides immediate feedback, but general skills develop over a long period.
Thanks for your attention!

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11:30-12:30

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