Towards coherence in STEM education: consequences for design

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Sciences and mathematics in NL

• Tradition in the Netherlands:
  • Primary school (K-6)
    ▪ Mathematics
    ▪ World orientation: science, geography, history
  • Middle school (grades 7-9)
    ▪ Mathematics
    ▪ Mainly separate sciences (ph/bi/ch) and technology
  • High school (grades 10-12, pre-university stream)
    ▪ Mathematics obligatory for all
    ▪ Separate sciences: chemistry, physics, biology
      (only for science tracks, requirements for STEM programs in higher education)
Factors against integration

- ‘Grammar of schooling’ (Venville et al., 2002):
  - Teacher identity
  - Teacher knowledge
  - Teacher communities
  - Subject histories
  - Assessment structures
  - Content-laden curricula
  - Subject status

- Support of professional societies
Arguments in favour of integration (1)

• Knowledge is unified, disciplines artificial

• Separate subjects:
  • contribute to unrealistic images of disciplines
  • restrict student thinking:
    ▪ they make the process of learning artificial
    ▪ they alienate students from life experiences

• Integrated courses more attractive to students
Arguments in favour of integration (2)

• New interdisciplinary study programs, in Dutch higher education e.g.:
  * Cognitive neuroscience
  * Forensic science
  * Environmental science
  * Drug innovation
  * Molecular life sciences
  * Biomedical science
  * Science and business
  * Marine technology
  * Human technology interaction
  * Bioinformatics
Arguments in favour of integration (3)

• Many issues in research and technology require an interdisciplinary approach, e.g.:
  • Fundamentals of processes of life
  • Self-healing materials:
    Asphalitic materials  Paints and other coatings
    Bio-inspired technical materials  Structural polymers
    Cementitious materials  Composites and hybrids
  • System earth: geoscience, climate and ocean science
  • Nanomaterials: fundamentals and applications
  • Bio- and medical technologies
  • Development of personalised medicines

• Industry needs T-shaped persons
A T-shaped person?
T-shaped persons?
The concept ‘T-shaped persons’ is a metaphor used in job recruitment to describe the abilities of persons in the workforce.

- **Vertical bar:** the depth of related skills and expertise in a single field.
- **Horizontal bar:** the ability to collaborate across disciplines with experts in other areas and to apply knowledge in areas of expertise other than one's own; this requires empathy and enthusiasm about other people’s disciplines.

(Tim Brown, IDEO CEO, 2010)
Three types of integration

• Multidisciplinary:
  • Students are expected to make the connections between subject areas themselves

• Interdisciplinary:
  • Subjects are interconnected beyond a theme or issue, connections are made explicit to students

• Transdisciplinary:
  • Begins with a real-life context; disciplines contribute implicitly to understanding the issue
Examples from the past (1960-1980)

Variety of unifying themes:

• Energy and Society: Investigations in Decision Making
  (US; BSCS; 1974/77; age 16-18)

• Project for an Energy-enriched Curriculum
  (US; NSTA; > 1977; age 6-18)

• Science in Society
  (UK, ASE; >1977; age 16-18)

• Schools Council Integrated Science Project: Patterns
  (UK; 1969/75; age 13-15)

• FUSE
  (US; Center for Unified Science Education; > 1968; age 5-18)

• Science A Process Approach
  (US; early 60s; age 5-12)
Recent example: China
(Sun, Wang, Xie & Boon, 2013)

- 2004: integrated science curriculum in junior high schools in provinces Hubei, Hunan and Shanghai
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• 2004: integrated science curriculum in junior high schools in provinces Hubei, Hunan and Shanghai
• 2009: return to compartmentalized science instruction because of:
  • Teachers’ qualifications: lack of content knowledge, no awareness of balance, inadequate training
  • Textbooks: lack of teaching resources
  • Assessments not integrated
  • Parental pressure
Recent example:
Twenty First Century Science (UK)(1)

• a suite of GCSE (age 14-16) science courses being taught in around 1000 schools in England and Wales
• developed in collaboration with teachers, schools and colleges
• the suite develops the scientific literacy of citizens and prepares those young people who opt for it for more advanced studies in science

http://www.twentyfirstcenturyscience.org/
Twenty First Century Science (UK)(2)

- **GCSE Science** - This course is not only about 'what we know' but also about 'how we know' and 'why knowing these things is important'. Students learn about the science that dominates public debates and touches everybody’s lives: such as genetics, air quality, earth and space, climate change, and vaccination.
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- **GCSE Additional Science** – This is a concept-led course to meet the needs of students seeking a deeper understanding of basic scientific ideas. The topics in this course complement those in the GCSE Science course, and together these courses prepare students for progression in the sciences in senior high school.
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- **GCSE Additional Applied Science** – This course meets the needs of students who wish to develop their understanding through authentic, work-related contexts. The course focuses on procedural and technical knowledge underpinning the work of practitioners of science.
Recent example: SALVO (NL)

- Since 2003: example materials for students and teachers in math and science (mainly physics) for grades 8-11
- Focus: relations between variables
- Some topics:
  - ratio
  - exponential functions
  - inverse relations
  - periodic functions
  - sound and vibration
  - working with formula

Workshop today, after lunch break
Recent example: NLT (NL)

- Advanced science and mathematics course, in addition to separate sciences and mathematics courses
- Senior high school (age 16-18)
- Covers wide area of recent developments in science and technology
- > 70 units, each 40 student hours
## Examples of NLT modules

<table>
<thead>
<tr>
<th>Drug innovation</th>
<th>Heart and arteries</th>
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<td>Dynamic modelling</td>
<td>Nuclear fusion</td>
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<td>Hydrogen car</td>
<td>Ice and climate</td>
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<tr>
<td>Medical imaging</td>
<td>Blue energy</td>
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<td>Molecular gastronomy (E)</td>
<td>Sound design</td>
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<td>CO2 storage</td>
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<td>Molecules of life (E)</td>
<td>Brains and learning</td>
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<td>Biosensors</td>
<td>Science and sport</td>
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<td>Crime science</td>
<td>Alcohol and traffic</td>
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<td>Climate change</td>
<td>Biomedical technology</td>
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<td>Detecting stars</td>
<td>Food or fuel (E)</td>
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<td>Purified drinking water</td>
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• Advanced science and mathematics course, in addition to separate sciences and mathematics courses
• Senior high school (age 16-18)
• Covers wide area of recent developments in science and technology
• > 70 units, each 40 student hours
• Taught by interdisciplinary teams of teachers

See workshop later this morning (Berenice Michels & Harrie Eijkelhof)
Recent example: science and statistics (NL)

- PhD research just completed (Adri Dierdorp)
- NLT-module bridging mathematics and science
- Learning correlation and regression in authentic contexts (professional practices):
  - sport physiologist: (an)aerobic metabolism
  - monitoring dyke heights
  - calibrating measuring devices (thermometers)
Recent example: science and statistics (NL)

**Heart rate vs speed**

**Dyke deformation vs time**
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- Learning correlation and regression in authentic contexts (professional practices):
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  - monitoring dyke heights
  - calibrating measuring devices (thermometers)
- Topics:
  - Informal inferences using correlation and regression
  - Reasoning about variability
  - Conceptual development of sampling
Programme for International Student Assessment (PISA)

• Created in 1997 by OECD
• Aim: to monitor outcomes of educational systems in terms of student achievement
• Age 15
• Surveys every 3 years since 2000, in reading, mathematical and scientific literacy
  • 2000 reading, math, science [43]
  • 2003 reading, math, science [41]
  • 2006 reading, math, science [57]
  • 2009 reading, math, science [65]
  • 2012 reading, math, science [65]
  • 2015 reading, math, science [?? ]
PISA 2015 Scientific Literacy Framework

Competencies
- Explain phenomena scientifically
- Evaluate and design scientific enquiry
- Interpret data and evidence scientifically

Knowledge
- Content
- Procedural
- Epistemic

Attitudes
- Interest in science
- Valuing scientific approaches to enquiry
- Environmental awareness

Contexts
- Personal
- Local/national
- Global
PISA 2015 Scientific competencies

1. Explain phenomena scientifically
2. Evaluate and design scientific enquiry
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## PISA 2015 Contexts

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<td><strong>Health</strong></td>
<td>Maintenance of health, accidents, nutrition</td>
<td>Control of disease, social transmission, food choices, community health</td>
<td>Epidemics, spread of infectious diseases</td>
</tr>
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<td><strong>Natural Resources</strong></td>
<td>Personal consumption of materials and energy</td>
<td>Maintenance of human populations, quality of life, security, production and distribution of food, energy supply</td>
<td>Renewable and non-renewable natural systems, population growth, sustainable use of species</td>
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<td><strong>Environmental Quality</strong></td>
<td>Environmentally friendly actions, use and disposal of materials and devices</td>
<td>Population distribution, disposal of waste, environmental impact</td>
<td>Biodiversity, ecological sustainability, control of pollution, production and loss of soil/biomass</td>
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<td><strong>Hazards</strong></td>
<td>Natural and human-induced decisions about housing</td>
<td>Rapid changes [earthquakes, severe weather], slow and progressive changes [coastal erosion, sedimentation], risk assessment</td>
<td>Climate change, impact of modern warfare</td>
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<td><strong>Frontiers of Science and Technology</strong></td>
<td>Scientific aspects of hobbies, personal technology, music and sporting activities</td>
<td>New materials, devices and processes, genetic modifications, health technology, transport</td>
<td>Extinction of species, exploration of space, origin and structure of the Universe</td>
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Scientific knowledge in PISA 2015

Of science:
- Physical systems
- Living systems
- Earth and space systems
Scientific knowledge in PISA 2015

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About science:
- Procedural knowledge: variables, measurement, replicability, representing data, control of variables
- Epistemic knowledge: purposes, nature, values, justification, errors, collaboration and critique
Attitudes in science (PISA 2015)

• Interest in science:  
ed.g. curiosity, willingness to acquire knowledge, career aspirations

• Valuing scientific approaches to enquiry:  
ed.g. commitment to evidence, criticism

• Environmental awareness:  
ed.g. concern, disposition to sustainable behaviour
Recent example in US: Framework for K-12 Science Education (NRC, 2012)

• Proposal to integrate in science standards:
  ▪ Core ideas (disciplinary knowledge)
  ▪ Science, Technology and Engineering practices: e.g. asking questions and defining problems, construction explanations, engaging in argument from evidence
  ▪ Crosscutting concepts: e.g. patterns; scale, proportion and quantity; systems and system models; stability and change

• Some links with mathematics in practices: using mathematics and computational thinking
The three spheres of activity for scientists and engineers in F K-12 SE

- **THE REAL WORLD**
  - ask questions,
  - observe,
  - experiment,
  - measure

- **COLLECT DATA**
  - TEST SOLUTIONS

- Investigating

- **THEORIES AND MODELS**
  - imagine,
  - reason,
  - calculate,
  - predict

- **FORMULATE HYPOTHESES**
  - PROPOSE SOLUTIONS

- Developing Explanations and Solutions

- Analyze

- Evaluating
Variety of ways to integrate disciplines in education

- National curriculum
  - China
- Alternative courses
  - 21st Century Science (UK); NLT (NL)
- Bridging materials
  - Salvo; science and statistics unit (NL)
- International frameworks
  - PISA (OECD)
- National Framework
  - Next Generation Science Standards (US)
How to bring coherence in STEM?

- Show similarities in procedural and epistemic knowledge and their relevance to understand scientific results
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- Highlight some differences in approach of disciplines, e.g. biology versus physics
- Illustrate position of science in society
- Highlight state of current research in some STEM-areas
- Promote interest in STEM among students (and the public)
Roads to coherence in STEM education

• Coherence is most important, roads may vary

• Extreme positions (full integration versus complete separation) are not positive for the development of science and math education:
  ▪ Too one-sided
  ▪ Battling is often a waste of energy
  ▪ Not all impediments can be resolved easily

• Explore a variety of ways to bring coherence
Further recommendations

• Take into account factors such as:
  ▪ Level of education
  ▪ Aims of the course
  ▪ Expertise of teachers
  ▪ Opportunities for professional development
  ▪ Available materials
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• Encourage cooperation of teachers in interdisciplinary teams
Finally

• Research is needed:
  - Effective materials
  - Proper assessment
  - Professional development of teachers (PCK)
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• International cooperation:
  ▪ Exchange ideas, materials, experiences and research results
Some references


