STEM Education: A Global Emphasis

- **Trends in International Mathematics and Science Study (TIMSS)**
  (4th and 8th grade students)
  U.S. Ranking

- **Program for International Student Assessment (PISA)**
  (15-year-old school children)
  U.S. Ranking

*International Studies: Opportunities for New Research*
Math enthusiasts are being challenged to answer a sample question from Chinese university entrance tests. The tests are set for prospective science undergraduates. The UK’s Royal Society of Chemistry is offering a £500 prize to one lucky but bright person who answers the question below correctly.

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### National test set by Chinese education authorities for pre-entry students

As shown in the figure, in square prism $ABCD-A_1B_1C_1D_1$, $AB=AD=2$, $DC=2\sqrt{3}$, $AA_1=\sqrt{3}$, $AD\perp DC$, $AC\perp BD$, and foot of perpendicular is $E$.

(i) Prove: $BD\perp A_1C$.

(ii) Determine the angle between the two planes $A_1BD$ and $BC_1D$.

(iii) Determine the angle formed by lines $AD$ and $BC_1$ which are in different planes.

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### Diagnostic test set by an English university for first year students

In the diagram (not drawn to scale), angle $ABC$ is a right angle, $AB = 3m$, $BC = 4m$.

(i) What is the length of $AC$?

(ii) What is the area of triangle $ABC$ (above)?

(iii) What is the $\tan\theta$ of the triangle $ABC$ (above) as a fraction?
Physics Questions in Chinese University Entrance Test (20~25 questions in 2 hrs)

Frame is made with resistance wire. Which situation gives largest \(|V_{ab}|\)?

![Diagram of four options A, B, C, D]

Give \(M_A, M_A,\) and \(m_{block}\. All surfaces are frictionless. How high does the block rise on B?\n
Give \(N, q, m,\) Area, L, no collision (diluted). Time to clean? Work done to particles? When is \(KE_{\text{particle}} = \text{Max}\)?

Given \(\Delta t_1, \Delta t_2\. Ask for \(\omega =?\ Which way the head moves to? \(\Delta t_3 =?\)
Learning from our collaborators

- Different approaches that may bring new ideas and field tested experiences for our development.
The content requirements for the high school teacher education program

The required courses in the physics department of Huazhong Normal University are listed as following.

• Mandatory courses:
  – Advanced Mathematics A(1,2), Linear Algebra A,
  – Mechanics, Thermodynamics and molecular physics, Optical, Static Electricity and magnetism, Analytical mechanics, Methods of mathematical physics, Atomic Physics, Electrodynamics, Quantum Mechanics, Statistical physics, Analog Electronics; Physics Experiments Level 1, 2, 3. Analog Electronic Experiments.
  Credits for the above courses total to 65.
  – 16-credits of professional education courses such as introductory education, psychology, teaching in physics, physics teaching skills, and modern educational technology.

• Elective courses: 24 credits including advanced physics courses, professional education courses, teaching practice, and graduation design.
### Science Teacher Education and Preparation

#### Science Education Master Program in Physics

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Credits</th>
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</thead>
<tbody>
<tr>
<td>Astron 291</td>
<td>Astrophysics</td>
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</tr>
<tr>
<td>Geog 520</td>
<td>Climatology</td>
<td>5</td>
</tr>
<tr>
<td>Phys 131</td>
<td>Particles &amp; Motion</td>
<td>5</td>
</tr>
<tr>
<td>Phys 132</td>
<td>Electricity &amp; Magnetism</td>
<td>5</td>
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<td>Phys 133</td>
<td>Thrm, Waves, &amp; Quant</td>
<td>5</td>
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<td>Phys 261</td>
<td>Dyn of Part &amp; Waves I</td>
<td>4</td>
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<td>Phys 262</td>
<td>Dyn of Part &amp; Waves II</td>
<td>4</td>
</tr>
<tr>
<td>Phys 263</td>
<td>Dyn of Part &amp; Waves III</td>
<td>4</td>
</tr>
<tr>
<td>Phys 517</td>
<td>Intro Electronics</td>
<td>4</td>
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<tr>
<td>Phys 670</td>
<td>Physics for Teachers</td>
<td>3-5</td>
</tr>
<tr>
<td>(or 108)</td>
<td></td>
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</tr>
</tbody>
</table>
In China in 2008, the gross enrollment ratios are 99.5%, 98.5%, and 74% respectively in elementary, junior secondary, senior secondary schools.
Student to teacher ratio

### Student-Teacher Ratio in China

<table>
<thead>
<tr>
<th>Grade</th>
<th>2000</th>
<th>2003</th>
<th>2004</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
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<tbody>
<tr>
<td>Grade1-6</td>
<td>22.8</td>
<td>21.0</td>
<td>20.5</td>
<td>19.8</td>
<td>19.5</td>
<td>18.8</td>
<td>18.4</td>
</tr>
<tr>
<td>Grade7-9</td>
<td>19.1</td>
<td>19.3</td>
<td>18.8</td>
<td>17.9</td>
<td>17.3</td>
<td>16.5</td>
<td>16.1</td>
</tr>
<tr>
<td>Grade10-12</td>
<td>15.6</td>
<td>18.4</td>
<td>19.2</td>
<td>19.6</td>
<td>19.8</td>
<td>19.9</td>
<td>19.5</td>
</tr>
</tbody>
</table>

### Student-Teacher Ratio in the U.S.

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Grade1-6</td>
<td>17.0</td>
<td>15.6</td>
<td>15.8</td>
<td>15.5</td>
<td>15.5</td>
<td>15.0</td>
<td>14.9</td>
<td>14.6</td>
</tr>
<tr>
<td>Grade7-9</td>
<td>16.5</td>
<td>15.9</td>
<td>16.3</td>
<td>15.5</td>
<td>15.5</td>
<td>15.2</td>
<td>15.1</td>
<td>14.7</td>
</tr>
<tr>
<td>Grade10-12</td>
<td>16.2</td>
<td>15.8</td>
<td>14.1</td>
<td>15.6</td>
<td>15.6</td>
<td>16.0</td>
<td>16.0</td>
<td>15.7</td>
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</table>
Percentage of teachers with required degrees.

**Teachers' Degree Qualified, China**

<table>
<thead>
<tr>
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<th></th>
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</thead>
<tbody>
<tr>
<td>Elementary</td>
<td>94.6%</td>
<td>96.9%</td>
<td>97.9%</td>
<td>98.6%</td>
<td>98.9%</td>
<td>99.3%</td>
</tr>
<tr>
<td>Junior Secondary</td>
<td>83.4%</td>
<td>87.0%</td>
<td>92.0%</td>
<td>95.2%</td>
<td>96.3%</td>
<td>97.8%</td>
</tr>
<tr>
<td>Regular Senior</td>
<td>63.5%</td>
<td>68.4%</td>
<td>75.7%</td>
<td>83.5%</td>
<td>86.5%</td>
<td>91.6%</td>
</tr>
<tr>
<td>Vocational Senior</td>
<td>37.4%</td>
<td>44.3%</td>
<td>59.4%</td>
<td>67.7%</td>
<td>71.9%</td>
<td></td>
</tr>
</tbody>
</table>

**Percentage of Teachers' Degree, US**

- Below bachelor: 5.6%
- Bachelor: 47.9%
- Master: 2.0%
- Edu specialist: 2.6%
- Doctorate or first professional: 42.0%
Issues in STEM Education

• Concerns in China
  – Too much content training
  – Lack of real world problem solving skills
  – Loss of interests in learning among college students

• Concerns in USA
  – Behind expected performance level in science and mathematics
  – “Fear” of science and mathematics

• Common goals in education “reform”
  – Balance STEM content learning and ability developing
  – Enable the new generation with the right set of knowledge, skills, and attitudes so that they not only become effective problem solvers but also good “problem creators”.

Currently both countries seem to be moving towards each other. The solution is probably in the midway.
Knowledge and Reasoning

- What people know
- What people can do

Scientific Reasoning:
- Domain general skills

Example
Identify and control variables
- universally needed in all science disciplines

Scientific Methods
- Observation
- Research Question
- Hypothesizing
- Experimentation
- Data Interpretation & Evaluation
Assessment of Scientific Reasoning

• **Ability Dimensions:**
  – Conservation of volume and mass
  – Proportional reasoning
  – Probabilistic reasoning
  – Control variables
  – Correlation reasoning
  – Hypothesis deductive reasoning and hypothesis testing/evaluation

• **Test Format**
  – MC type
  – Paired question and explanation
The Lawson’s Scientific Reasoning Test
Does STEM content learning affect the development of scientific reasoning abilities?

- **Main variables:**
  
  **K-12 training on science and mathematics**
  - Chinese Students (5~6 years of physics courses, mandatory, complex level)
  - US Students (1~2 semesters' of physics, elective, basic level)

- **Measures:**
  
  - FCI, BEMA* – STEM content
  - Scientific Reasoning (24Q, MC)

* FCI – force concept inventory (mechanics, 30Q, MC)
  BEMA – brief electronic and magnetism assessment (E&M, 31Q, MC)
The FCI and BEMA Tests

A neutral metal bar is moving at constant velocity $v$ to the right through a region where there is a uniform magnetic field pointing out of the page. The magnetic field is produced by some large coils which are not shown on the diagram.

Q30 Which of the following diagrams best describes the state of the metal bar?

(a) ![Diagram (a)](image)
(b) ![Diagram (b)](image)
(c) ![Diagram (c)](image)
(d) ![Diagram (d)](image)
(e) ![Diagram (e)](image)
(f) ![Diagram (f)](image)
(g) ![Diagram (g)](image)

Battery

A

Light bulb

B

C

D

E
First Year College Students’ FCI Results

Population Percentage

FCI Score

China
USA

0% 5% 10% 15% 20% 25% 30%

0 5 10 15 20 25 30
First Year College Students’ BEMA Results

Population Percentage vs. BEMA Score for China and USA
First Year College Students’ Lawson Results

<table>
<thead>
<tr>
<th>Populations</th>
<th>Sites</th>
<th>N_{Total}</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>US (11+12)</td>
<td>11</td>
<td>402</td>
<td>15.4</td>
<td>3.9</td>
</tr>
<tr>
<td>CN (11+12)</td>
<td>39</td>
<td>1786</td>
<td>15.1</td>
<td>3.7</td>
</tr>
<tr>
<td>US (U. 1\text{st})</td>
<td>7</td>
<td>1061</td>
<td>17.8</td>
<td>4.3</td>
</tr>
<tr>
<td>CN (U. 1\text{st})</td>
<td>5</td>
<td>369</td>
<td>17.9</td>
<td>3.8</td>
</tr>
</tbody>
</table>
The Developmental Scale of Scientific Reasoning

Measure and obtain a developmental metric of Lawson’s test results for K-17 students.

- Over 10,000 data points from China
- ~3,000 from US college students
- ~2,500 from US K-12 students.
Learning Evolution Index (LEI) Curve

\[ y = F + \frac{C - F}{1 + e^{-\alpha(x - b)}} \]

- \( C = 19.9 \) (83%)
- \( F = 4.82 \) (20%)
- \( \alpha = 0.47 \)
- \( b = 9.68 \)
LEI Curve for “Control of Variables”

\[
y = F + \frac{C - F}{1 + e^{-\alpha(x - b)}}
\]
LEI Curve for “Hypothetical-Deductive”

\[ y = F + \frac{C - F}{1 + e^{-\alpha(x - b)}} \]

- \( C \) = 0.82
- \( F \) = 0.24
- \( \alpha \) = 0.82
- \( b \) = 10.7

Graph showing ChinaData and USdata with a fit line and equation.
LEI Curve for “Proportional Reasoning”

Proportional Reasoning

Grade Level

ChinaData

USdata

Fit

Equation:

\[ y = F + \frac{C - F}{1 + e^{-\alpha(x-b)}} \]

Parameters:

- \( C = 0.86 \)
- \( F = 0.05 \)
- \( \alpha = 0.50 \)
- \( b = 8.2 \)
LEI Curve for “Probabilistic Thinking”

\[
y = F + \frac{C - F}{1 + e^{-\alpha(x-b)}}
\]

- **ChinaData**: Fit
- **USdata**: C 0.79, F 0.19, \(\alpha\) 0.50, b 10.4
What methods are effective in developing Scientific Reasoning abilities?

Under current education settings the learning of content knowledge doesn’t seem to have an obvious effect on the development of general scientific reasoning abilities. 
- Regular intro courses has no effect (effect size~0.1).
- Inquiry-based courses changes Lawson pre-post (effect size=0.4~1).

<table>
<thead>
<tr>
<th></th>
<th>Course A</th>
<th></th>
<th>Course B</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>Pre-Test</td>
<td>205</td>
<td>60.5%</td>
<td>19.3%</td>
</tr>
<tr>
<td>Post-Test</td>
<td>197</td>
<td>61.5%</td>
<td>19.9%</td>
</tr>
<tr>
<td>Pre-Post Difference</td>
<td></td>
<td>1.0%</td>
<td></td>
</tr>
<tr>
<td>Pre-Post Effect Size</td>
<td></td>
<td>0.05</td>
<td></td>
</tr>
</tbody>
</table>

It is not what we teach but how we teach that matters!
Current Research

• Develop a valid and easy-to-use assessment tool (a test bank of 300+ questions).
• Develop curriculum.
• Evaluate the effectiveness of several education programs.
• Develop a large scale national and international quantitative assessment database.
• Develop a community of users and researchers.

(NIH STEM Edu)
Eye-tracking Measurement
Sustained Development: community building

- About 12 Universities and 50 schools in China
- About 8 Universities and 30 schools in USA
- Additional Countries: Germany, India, Israel, Japan, South Africa, South Korean, Thailand
Community Building

Journal: Research in Education Assessment and Learning
www.iperc.org/REAL

REAL: Research in Education, Assessment, and Learning
ISSN: 1947-5497

REAL is a free electronic journal, accessible at http://www.iperc.net/REAL.

REAL publishes original papers on research in education, assessment, and learning. REAL encourages reports of both quantitative and qualitative studies on education in Science, Technology, Engineering, and Mathematics (STEM).

STEM education is emphasized worldwide as the core thrust for a sustainable globalized economy. REAL welcomes contributions from researchers and teachers around the globe. The main goal of REAL is to help fostering an active and healthy international community of researchers, teachers, and learners of all backgrounds interested in education.

Planning Editor: Lei Bao

Editorial Board (developing):
Lei Bao, Tianfang Cai, Dawey Dykstra, Kai Fang, Yuying Guo, Kathy Koenig, Ying Luo, Yan Tu, Nianli Wu, Zuren Wu, Ying Yun

Contact: This e-mail address is being protected from spambots. You need JavaScript enabled to view it.

The first issue of REAL will contain papers presented on the IPERC Workshop on International Education Research, which will be held on July 21-26 at The Ohio State University.

Author guidelines and paper styles will be provided soon. We have started accepting manuscripts. Our targeted turnaround time for manuscript reviewing is two months. The average publishing time is targeted at 3–6 months from submission to publication. The access of the journal is free of charge.
Community Building

IPERC and CAER Joint Summer Meeting
August 5-7, 2010 in Beijing China

Chinese Association of Education Research (CAER)
Chinese Physical Society (CPS)
International Commission on Physics Education (ICPE)