Improving the Preparation of Secondary Mathematics and Science Teachers

Submitted by: Harvard University
Improving the Preparation of Secondary Mathematics and Science Teachers

Identifying Best Practices in Mathematics and Science: Teacher Preparation in APEC Economies

Jon R. Star, Ph.D.
Harvard University

Changes....

• Changes in our world require changes in our teachers, especially in mathematics and science.
Changes in....

• **What** teachers teach
  – New discoveries and the needs of the marketplace change what teachers are expected to teach and thus what teachers need to know

• **How** teachers teach
  – Advances in the science of effective pedagogies

• **Technologies** that may aid teaching
  – Smartboards, computers, calculators, the Internet, and online learning

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Crucial at Secondary Level

• Pace of change is **most rapid** in secondary, both in **content** and **pedagogy**.
  – Because courses are most advanced, it is necessary to incorporate newest content discoveries.
  – After years of focusing on elementary, recent attention and research are on improving teaching in secondary.

• Secondary represents our best (and last) chance to **encourage** students to go to college and **pursue STEM** majors and careers.
Implications

• These changes in our world, and the changing landscape of teaching mathematics and science, have profound implications for:
  – recruitment of teachers
    • Increasingly qualified candidates to teach secondary mathematics and science are difficult to find.
  – training of teachers
    • Our teacher education programs need to respond to these changes.

Given the significant challenges that we face in improving our teacher education programs (including adapting existing programs, designing new programs, and evaluating the effectiveness of our programs), sharing promising practices in secondary mathematics teacher education can be both efficient and helpful.
Unique Contribution

• This project fills an important knowledge gap in teacher preparation programs.
• No major international study has:
  – examined secondary mathematics and science teacher education programs;
  – identified promising practices in teacher preparation; and
  – assessed the knowledge needed to effectively teach secondary mathematics and science.

Participating Economies

(Original project members shaded in orange)
University-Driven Project

APEC Project Sponsors: U.S.ED & Columbia Univ
Lead universities include:
- Australia: Monash University
- China: East China Normal
- New Zealand: Waikato University
- Russia: Moscow Institute of Open Education
- Singapore: National Institute of Education
- Thailand: Koen Kaen University
- USA: Columbia, Harvard and Pennsylvania
- Leads will be established for Chile, Hong Kong, Japan and Peru

Project Activities

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<th>Economy Context</th>
<th>Teacher Preparation (Sample of Institutions)</th>
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February 2012
Asia-Pacific Economic Cooperation Education Network

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#### Key Questions
- What are key characteristics of the economy’s education systems?
- What are key characteristics of teacher education schools?

#### Key Questions
- What are the math/science standards?
- How do standards address 21st century challenges (math/science for all, use of technology, real-world issues)?

#### Key Questions
- What are the institution's secondary math/science educational objectives?
- What is the students’ course preparation plan to meet these objectives?

#### Key Questions
- What are promising practices in improving the content or pedagogical preparation of secondary math/science teachers?
- What is the prospective teachers' level of:
  - high school student math content knowledge;
  - advanced math content knowledge; and
  - pedagogical content knowledge?
Sample Participant Economy **PROFILES:**
Current Project Participants and PISA Scores

**Programme for International Student Assessment (PISA) Rankings for Mathematics and Science**

<table>
<thead>
<tr>
<th>Developed Economy</th>
<th>Math Score (Rank)</th>
<th>Science Score (Rank)</th>
<th>Developed Economy</th>
<th>Math Score (Rank)</th>
<th>Science Score (Rank)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Singapore</td>
<td>562 (2)</td>
<td>549 (3)</td>
<td>Shanghai, CN</td>
<td>600 (1)</td>
<td>575 (1)</td>
</tr>
<tr>
<td>Hong Kong, CN*</td>
<td>555 (3)</td>
<td>542 (4)</td>
<td>Russia</td>
<td>468 (38)</td>
<td>478 (39)</td>
</tr>
<tr>
<td>Japan*</td>
<td>529 (9)</td>
<td>539 (5)</td>
<td>Chile*</td>
<td>421 (49)</td>
<td>447 (44)</td>
</tr>
<tr>
<td>New Zealand</td>
<td>519 (13)</td>
<td>532 (7)</td>
<td>Thailand</td>
<td>419 (50)</td>
<td>425 (49)</td>
</tr>
<tr>
<td>Australia</td>
<td>514 (15)</td>
<td>527 (10)</td>
<td>Peru*</td>
<td>365 (63)</td>
<td>369 (64)</td>
</tr>
<tr>
<td>United States</td>
<td>487 (31)</td>
<td>502 (23)</td>
<td></td>
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* Added to original project membership.

**PROFILES:**
Students Not Graduating Upper Secondary Pose Special Challenges for Providing a Solid Math Foundation

upper Secondary Graduation Rate Under 25 and Upper Secondary Education Attainment Rates 25-34

Source: OECD 2011 Education At a Glance and 2011 Singapore Education Statistics Digest

- **Upper Secondary Graduation Rates 2009 Under 25**
- **Upper Secondary Attainment Rates 25-34**
**PROFILES:**
Secondary Teachers Salaries Relative to Average Economy GDP Affects the Quality of Teacher Entrants

Lower Secondary Teacher Salaries to GDP per Capita (2009)

Source: OECD 2011 Education At a Glance

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**PROFILES:**
How Big Is Class Size (Lower Secondary)?
Is Class Size Related to Student/Teacher Ratios?

Source: OECD 2011 Education At a Glance
STANDARDS:
To What Extent Do Secondary Mathematics Standards Address 21st Century Challenges?

- Building secondary mathematics content on the primary grade math foundation topics
- Adapting mathematics choices to individual student needs and abilities
- Understanding how to apply mathematics to solve real-world problems.
- Teaching mathematics areas (algebra, geometry, statistics) sequentially in different years or integrated within a year
- Making connections between mathematics and other subjects

STANDARDS:
Do Standards Incorporate Technology?

<table>
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<tr>
<th>National Curriculum Contains Policy Statements About Computers</th>
<th>National Teacher Preparation Technology Standards</th>
<th>Process to Assess Teachers on National Teacher Technology Standards</th>
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<tbody>
<tr>
<td>Australia</td>
<td>✔ Yes</td>
<td>✔ Yes</td>
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Source: National curriculum is TIMSS-8 2007 Ex. 7-11; U.S. Common Core Standards; Technology and teachers from: International Experiences With Technology in Education: Final Report; U.S. Department of Education. www2.ed.gov/about/offices/list/os/technology/iete-full-report.doc
STANDARDS:
Changing Distribution of Common Math Topics by Grade Span

Economies: Australia, Canada, China, Chinese Taipei, Hong Kong, Japan, Korea, Malaysia, New Zealand, Singapore, Thailand, and the United States

STANDARDS:
China Adapting Math Standards to Individual Student Needs
STANDARDS:
Real-World Math Applications: China Problem Examples

- Challenging applications begin in the early grades.
- Consider this problem from the standards of grades K-3:
  - What is the approximate thickness of 1,200 sheets of paper?
  - What is the approximate number of classes that may be formed comprising of 1,200 students?
  - What is the approximate length of 1,200 footsteps?

STANDARDS:
Problem on Secondary (Grades 10-12), Chinese Standards

According to the weather forecast, the probability that there will be a small flood in some place next month is 0.25, and the probability for a big flood is 0.01. Suppose that there is a piece of large equipment in a construction site and there are three plans to protect it from floods.

- Plan 1: Remove the equipment. This costs $38,000 Yuan.
- Plan 2: Construct a wall for protection. This costs $20,000 Yuan, but this wall cannot stop the big flood. When the big flood comes and the equipment is destroyed, the loss is $600,000 Yuan.
- Plan 3: No plan at all. When there is a big flood the loss is $60,000 Yuan. When there is a small flood the loss is $10,000 Yuan.

Which plan is better?
STANDARDS:
New Zealand Focus on Statistics From Primary to Secondary

- Unlike most economies, New Zealand (NZ) devotes about a third of its standards to statistics at every grade span. NZ scores well on PISA, a test of applications.
- NZ statistical inquiry cycle:
  - 5th Grade: Gathering, sorting, and displaying multivariate category data, discrete numeric data, and simple time-series data to answer questions.
  - 10th Grade: Planning and conducting their own surveys and experiments.
  - End of secondary school: Critiquing and refining the process of statistical enquiry using margins of error, experimental randomization schemes, data modeling, and more.

STANDARDS:
Integrated Versus Sequential Course Streams

*Integrated*: Singapore O & N (Lower & Upper) Secondary Math

*Secondary 1 (Req)*
- Numbers & Alg.
- Geometry & Meas.
- Stats. & Prob.

*Secondary 2 (Req)*
- Numbers & Alg.
- Geometry & Meas.
- Stats. & Prob.

*Secondary 3&4 (Req)*
- Numbers & Alg.
- Geometry & Meas.
- Stats. & Prob.

*Sec. 3&4 (Opt)*
- Additional topics incl. differentiation & integration calculus

*Sequential*: Texas Lower Secondary & Upper Secondary Math

*Grade 9*
- Algebra 1
- Geometry
- Math Models With Applications

*Grade 10*
- Algebra 2

*Grade 11*
- Pre-calculus
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ASSESSMENT:
The Challenge

- What does one need to know in order to be an effective teacher of secondary mathematics or science?
- Can we assess whether graduates of teacher preparation programs have begun to develop this knowledge?
- If so, what can we learn about teacher education from examining economy differences in performance on this assessment?

ASSESSMENT:
“Student-Level” Content Knowledge

Which of the following situations can be modeled using an exponential function?

i. The height $h$ of a ball $t$ seconds after it is thrown into the air.
ii. The population $P$ of a community after $t$ years with an increase of $n$ people annually.
iii. The value $V$ of a car after $t$ years if it depreciates $d\%$ per year.

A. i only  
B. ii only  
C. iii only  
D. i and ii only  
E. ii and iii only

Source: Released item, Knowledge for Teaching Algebra project, © 2005 Division of Science and Mathematics Education, Michigan State University
ASSESSMENT:
“Pure Content”

1. Prove that for all $z, z_1, z_2 \in \mathbb{C}$, $|\exp(z)| = \exp(\text{Re}z)$.
2. Evaluate $\exp(\log(3+4i))$.
3. Prove that $\exp(b \log a)$ is single-valued if and only if $b$ is an integer.

Again, this knowledge is necessary but not sufficient.

ASSESSMENT:
“Pedagogical Content Knowledge”

- PCK: “a kind of understanding [that] is not something a mathematician would have, but neither would be part of a high school social studies’ teacher’s knowledge” (Ball & Bass, 2000)
- What makes a particular concept difficult to learn
- What misconceptions lead to specific mathematical errors
- What examples or representations might be most helpful to students

A student solves the equation $4^x = 16(4^{-x})$ and gets the answer $x = 0$. What might the student have done wrong?

How much of the drug remains active at the end of the first day?

Source: PISA 2003 Assessment and Framework, p. 83

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Figure 1. Grade 1 student gains by teacher CKT-M.
ASSESSMENT:  
Teacher Knowledge

• Intuition and research suggest that there are several kinds of knowledge that are especially important for mathematics and science teachers.

• Teachers need to understand:
  – the content that students will be learning;
  – ways to represent and explain this content so that it is accessible to students; and
  – the trajectory of this material in advanced study in the content area.

• An assessment needs to measure all of these.

ASSESSMENT:  
Our Plan

• Questions based on PISA
  – Student-level content from PISA
  – Develop ‘pure content’ extensions of PISA questions
  – Develop PCK items from PISA questions

• Within each type, a subset of items that are common to all economies to allow for some comparisons across economies
  – But each economy can select the remainder of the items based on its own
  – Each economy can also supplement short answer extension questions to examine pedagogy
ASSESSMENT:
Logistics

• Short assessment (an hour or less)
• Easy to administer and grade
  – Translation and grading done by each economy
• Administered to graduating prospective teachers
  in secondary mathematics and science
  – Southern hemisphere: late Fall, 2012
  – Northern hemisphere: Spring, 2013

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