Standing on the Shoulders of Giants: Using the Lessons of Science to Prepare and Retain Skilled Teachers of Science

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Utah State University
The Shoulders of Giants...

Matthew  Mark  Luke  John

Isaiah  Jeremiah  Ezekiel  Daniel

Chartres Cathedral
Sir Isaac Newton
Calculus ● Law of Universal Gravity ● Reflecting Telescope ● Laws of Motion

If I have seen further than others, it is by standing upon the shoulders of giants.
Utah’s Secondary Science Workforce
(per USOE, 2012-13)

1209 (82%)

180 (12%)

81 (6%)

Legend:
- Light Green: Licensed
- Light Blue: Letter of Authorization
- Light Red: State Approved Plan
Teacher Shortage

• Districts around the state are facing a teacher shortage

• Specifically for math, physics, and chemistry (U.S. Dept. of Education, 2015)
  – Mathematics teachers: 15 out of 16 years
  – Chemistry teachers: 9 out of 16 years
  – Physics teachers: 7 out of 16 years
### Survey: Workforce Demand & Satisfaction

<table>
<thead>
<tr>
<th>District</th>
<th># of Science Teachers</th>
<th>Approximate annual hires</th>
<th>District Size</th>
<th>Satisfaction with Quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wayne</td>
<td>2</td>
<td>&lt;1</td>
<td>Small</td>
<td>Unsatisfied</td>
</tr>
<tr>
<td>Rich</td>
<td>2</td>
<td>&lt;1</td>
<td>Small</td>
<td>Satisfied</td>
</tr>
<tr>
<td>Garfield</td>
<td>3.5</td>
<td>&lt;1</td>
<td>Small</td>
<td>Unsatisfied</td>
</tr>
<tr>
<td>N. Summit</td>
<td>4</td>
<td>&lt;1</td>
<td>Small</td>
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<tr>
<td>S. Summit</td>
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<td>Kane</td>
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<td>Juab</td>
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<td>Small</td>
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</tr>
<tr>
<td>Emery</td>
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</tr>
<tr>
<td>Carbon</td>
<td>9</td>
<td>0-2</td>
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<td>Millard</td>
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<td>&lt;1</td>
<td>Small</td>
<td>Satisfied</td>
</tr>
<tr>
<td>Wasatch</td>
<td>7-8</td>
<td>1</td>
<td>Small</td>
<td>Satisfied</td>
</tr>
<tr>
<td>Cache</td>
<td>12-15</td>
<td>1-2</td>
<td>Small</td>
<td>Satisfied</td>
</tr>
<tr>
<td>Park City</td>
<td>25</td>
<td>0-3</td>
<td>Medium</td>
<td>Satisfied</td>
</tr>
<tr>
<td>Iron</td>
<td>27</td>
<td>2</td>
<td>Medium</td>
<td>Satisfied</td>
</tr>
<tr>
<td>Ogden</td>
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<td>3-5</td>
<td>Medium</td>
<td>Satisfied</td>
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<td>Washington</td>
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<td>Medium</td>
<td>Satisfied</td>
</tr>
<tr>
<td>Provo</td>
<td>21-22</td>
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<td>Medium</td>
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<tr>
<td>Nebo</td>
<td>~65</td>
<td>n/a</td>
<td>Medium</td>
<td>Satisfied</td>
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<tr>
<td>Jordan</td>
<td>110</td>
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<td>Large</td>
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<td>Canyons</td>
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<td>20-30</td>
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<td>Davis</td>
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<tr>
<td>Alpine</td>
<td>150</td>
<td>21</td>
<td>Large</td>
<td>Unsatisfied</td>
</tr>
<tr>
<td>Granite</td>
<td>150</td>
<td>12</td>
<td>Large</td>
<td>Unsatisfied</td>
</tr>
</tbody>
</table>

*White*—No data  
*Purple*—Satisfied (small)  
*Green*—Satisfied (medium)  
*Red*—Unsatisfied (small & large)
Licensure Rates in Utah
(U.S. Dept. of Education, Title II data)

Licenses Recommended by Utah Programs

- Science Licensure
- Math Licensure
Utah Population Dynamics (NCES, 2014)

• School aged population in Utah increased 27.4% from 2000-2012
  – From 481,485 to 613,279

• Projected increase of 17.3% from 2012-2024
  – From 613,279 to 719,400
Teacher Education in Utah
(U.S. Dept. of Education, Title II data)

Total Enrollment

- 2008-2009: 5346
- 2009-2010: 9628
- 2010-2011: 11201
- 2011-2012: 9566
- 2012-2013: 9616
- 2013-2014: 7207
Teacher Education in Utah
(U.S. Dept. of Education, Title II data)

Total Enrollment by Program Type

- Regular Program
- Alternative

<table>
<thead>
<tr>
<th>Year</th>
<th>Regular Program</th>
<th>Alternative</th>
</tr>
</thead>
<tbody>
<tr>
<td>2008-2009</td>
<td>4581</td>
<td>765</td>
</tr>
<tr>
<td>2009-2010</td>
<td>9021</td>
<td>73</td>
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<tr>
<td>2010-2011</td>
<td>8511</td>
<td>595</td>
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<tr>
<td>2011-2012</td>
<td>9246</td>
<td>320</td>
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<td>2012-2013</td>
<td>9346</td>
<td>270</td>
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<tr>
<td>2013-2014</td>
<td>6869</td>
<td>338</td>
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</table>
Undergraduate Interest in Teaching Survey (n=1,432)

- 60% Not Interested
- 28% Interested in teaching but not pursuing
- 12% Pursuing Licensure
Undergraduate Interest in Teaching Survey (n=1,432)

- Interested in teaching but not pursuing: 28%
- Pursuing Licensure
- Not Interested
Interested in Teaching but Not Pursuing

<table>
<thead>
<tr>
<th>Licensure Area</th>
<th>Physics</th>
<th>Physical Science</th>
<th>Earth Science</th>
<th>Chemistry</th>
<th>Environ. Science</th>
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</thead>
<tbody>
<tr>
<td>B.S. Eng.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Mechanical Eng.</td>
<td>3/5</td>
<td>4/8</td>
<td>3/9</td>
<td>1/5</td>
<td>1/11</td>
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<tr>
<td>Biological Eng.</td>
<td>2/5</td>
<td>3/8</td>
<td>2/9</td>
<td>3/5</td>
<td>3/11</td>
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<tr>
<td>Civil Eng.</td>
<td>2/5</td>
<td>3/8</td>
<td>3/9</td>
<td>1/5</td>
<td>2/11</td>
</tr>
<tr>
<td>Computer/Electrical Eng.</td>
<td>3/5</td>
<td>2/8</td>
<td>2/9</td>
<td>0/5</td>
<td>1/11</td>
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<tr>
<td>Environmental Eng.</td>
<td>2/5</td>
<td>4/8</td>
<td>3/9</td>
<td>3/5</td>
<td>2/11</td>
</tr>
</tbody>
</table>
Undergraduate Interest in Teaching Survey

Reasons Interested Students Did Not Pursue K-12 Teaching (multiple response option)

- Too much additional time: 40.60%
- Require classes already taken: 23.60%
- Not enough pay: 57.50%
- No FinAid: 15.10%
- Process confusing: 18.90%
Failed Attempts to Increase Teacher Supply (Ingersoll & May, 2012)

• Troops to Teachers
• Teach for America
• Alternative Route to Licensure
• International recruitment
• Scholarships
• Loan Forgiveness
In the current environment, we will not recruit more people into teaching.

So, how can we keep more teachers once they start?
Teacher Attrition (Not Retirement)

Greatest attrition in science, mathematics, and special education
(Ingersoll, 2006)
Figure 3. Percentage of new teachers who left the profession and moved schools within their first 5 years by cohort, 1987 to 2001

Illinois data; DeAngelis & Presley (2011)
Major Contributors to Attrition

• Individual school working conditions (Allensworth et al., 2009; DeAngelis & Presley, 2011)

• Burnout (Aloe et al., 2014)

• Ineffective teachers leaving/counseled out (Boyd et al., 2007; Goldhaber et al., 2007)

• Not student characteristics, after controlling for working conditions (Loeb et al., 2005)
What do the factors have in common?

Teachers’ ability to perform under stress imposed by the job
Can Teacher Training Reduce Attrition?

Figure 4. Predicted Probability of Attrition of Beginning Teachers, by Various Pedagogy Packages: 2004-05

- Little or No Pedagogy: 24.6%
- Basic Pedagogy: 12.3%
- Basic Pedagogy Supervised Teaching Only: 9.9%
- Basic Pedagogy Plus 1 methods course: 9.8%
- Comprehensive Pedagogy: 9.8%

Ingersoll et al. (2014)
Current Teacher Training

• Training Outcomes
  – No correlation between quality of teacher preparation program and student achievement (Levine, 2006)
  – Novice teachers typically:
    • Feel overwhelmed by the amount of simultaneous classroom activity
    • Have great difficulty converting theory into practice in their classrooms
  – Experienced teachers typically see little connection between theory taught in their preparation programs and actual practice

• Training Processes
  – Little procedural knowledge provided to novices in university courses (Kagan, 1992)
  – 76% of teachers in the United States practice for no longer than one semester before going into the field (Levine, 2006)
Figure 2. Percent Beginning Teachers without Specific Types of Pedagogical Preparation, by Field: 2003-04

No Coursework in Teaching Methods: 18 (Other), 30 (Math), 35 (Science)
No Practice Teaching: 21 (Other), 23 (Math), 42 (Science)
No Preparation in Selecting Materials: 17 (Other), 20 (Math), 31 (Science)
No Coursework in Psych./Learning Theory: 15 (Other), 18 (Math), 26 (Science)
No Observation of Others’ Teaching: 12 (Other), 11 (Math), 18 (Science)
No Formal Feedback on Own Teaching: 17 (Other), 14 (Math), 26 (Science)
Why?

Psychological Science!
Cognitive Skill Acquisition

• **Three stage model** (Anderson, 1982, 1995)
  – Cognitive Stage
    • Dependence upon explicit declarative knowledge
    • Slow, effortful, and non-transferable
  – Associative Stage
    • Transformation to proceduralized knowledge
    • Faster and accurate, but vulnerable to task irregularities
  – Autonomous Stage
    • Procedural knowledge is fully automated
    • High speed, low mental effort, very difficult to change
Attention and Memory

• **Short term memory** (Cowan, 2001)
  – Conscious awareness
  – Very limited capacity (4 +/- 1 chunks)
  – Very limited duration (20-30 seconds)
  – Analogous to computer RAM
Audience Participation
Using the Space Well

• Organized knowledge takes up less space

• As skills are practiced, they take up less space
  – Habits are unconscious
What Kinds of Things Waste Space?

• Redundant or irrelevant information
• Background noise or activities
• Anxiety
What Happens When you Exceed the Limits?

When too much information needs to be processed:

• People miss details
  – No space available to notice

• People revert to old habits
  – “Smaller” elements are substituted for “larger” elements unintentionally
  – Procedures and goals can change
A Metaphor

- A bucket has a limited volume that it can hold.
- When choosing how to fill it, you can put in a few large objects or more smaller objects.
- Newer concepts and skills are large objects.
- Other information and distractions take up space in the bucket.
- Based on performance needs, choose carefully which objects should go in the bucket to ensure that all necessary items can fit.
The Dual Process Model of Cognition

Information processing occurs simultaneously on parallel pathways (Kahneman, 2013)

- Controlled pathway
  - Conscious, slow, effortful information processing
  - Accurate representation of instance-specific information

- Automatic pathway
  - Fast, effortless, nonconscious processing
  - Pattern recognition, heuristics, generalizations, and stereotypes
The Dual Process Model of Cognition

- Conflicting outcomes from pathways consciously mediated in working memory (e.g., Stroop)
  - If demands on working memory exceed capacity, nonconscious pathway outcome is default
Stroop Effect

GREEN

RED
Stroop Effect

LARGE

SMALL
The Dual Process Model of Cognition

- Cognitive shortcuts (heuristics) mitigate limitations of working memory
  - Automatic processes/stereotypic “templates” reduce quantity of information requiring working memory
  - May help or hinder performance
    - Permits other, task-relevant cognitive processing
    - Restricts conscious monitoring that detects and corrects performance errors
Cognitive Defaults and Ironic Mental Processes

• When working memory capacity is exceeded, effortful (newer) goals and procedures are replaced by more automated routines
  – Teachers teach as they were taught, not as they were trained to teach (Lortie, 1975; Nettle, 1998; Rich, 1990)

• Defaults occur outside of awareness
  – Of 116 novice teachers, most self-beliefs/self-reports did not match classroom behaviors
  – Discrepancies went undetected by participants (Simmons et al., 1999)
Examples (Feldon, 2007)

- Assignment of blame defaults to personality trait association under load
- Racial bias increases under extraneous load and speeded time constraints, regardless of articulated beliefs or intentions
  - Encoding personal trait information under load leads to stereotyping upon recall
- Pygmalion effect
  - Teachers’ perceptions of student ability are better predictors of grades than actual performance
Teachers’ Expertise Mediates Load

• Experienced teachers
  – Have robust/automatic routines
  – Are not overwhelmed by classroom activity
  – Differentiate relevant classroom cues more effectively
  – Do not evidence Pygmalion effect (>9 years)

• More automated, adaptive routines allow cognitive resources to be dedicated to uniquenesses and complexities.
Teachers’ Expertise Mediates Load

• Basic pedagogical skills, classroom management issues, and curricular content impose nearly all of the cognitive load that novice teachers can process successfully
  – Frequent failure to consider specific individual differences between students
  – Difficulty adapting when circumstances demand deviations from prepared lesson plans
  – Less successful interpreting and responding to nonverbal cues and retaining focus on long-term instructional goals
Implications for Teacher Training

• Complex tasks (e.g., teaching)
  – Multiple valid solutions
  – Cannot be mastered in a single session
  – Require the use of both conceptual knowledge and strategies/skills
  – Impose a very high load on learners’ cognitive system

• Reduce levels of unnecessary load with training
  – Decrease likelihood of defaults and burnout
Instruction and Knowledge

• Data from decades of studies of discovery learning and unguided problem-based learning indicate:
  – Achievement is poor when students are not provided with the information necessary to guide informed problem-solving decisions (Kirschner, Sweller, & Clark, 2006; Mayer, 2004)
  – Students are likely to become overwhelmed, confused, and lose motivation (Chandler & Sweller, 1991; de Jong & van Joolingen, 1998; Goodyear, et al., 1991; Kalyuga et al., 2003; Lewis et al., 1993)
  – Students who do succeed in discovery learning tasks do not demonstrate any advantage on later tasks compared to those who received explicit instruction (Klahr & Nigam, 2004)
Instruction and Knowledge

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The Effects of Instruction

• Bloom’s (1984) Two-Sigma Problem
  – Comparison of student achievement under conventional classroom teaching, mastery classroom teaching, and tutoring
    • Tutored students performed 2 standard deviations above the conventional classroom mean
      – 50th percentile in tutoring = 98th percentile in conventional
    • Tutored students had less variation in performance
      – 90% of scores fell into the same range as the top 20% of conventional
  – Correlations between intelligence and achievement
    • Conventional: $r = 0.60$
    • Tutoring: $r = 0.25$
What was Different?

• Mastery classroom teaching* and tutoring provided:
  – Detailed explanations
  – Individualized feedback to correct performance errors and close knowledge gaps

• In short, students were not forced to infer necessary knowledge to perform assessment tasks

*1.7 SD advantage over conventional
Cognitive Load and Instructional Support

- More instructional support = less extraneous load
- Less load = more available space for conscious processing
- More conscious processing = more retention
Structures for Teacher Training
Traditional Training Structure: Part-Whole Task

Methods + Classroom Management + Content + Assessment + Differentiation

Now do:
The Reality of Part-Whole for Teaching

Now do:
New Training Structure: Deepening Complexity

van Merrienboer (1997); van Merrienboer & Kirschner (2014)
Training Teachers

• Two key elements to avoid overload:
  – Detailed “how to” explanations
  – Guided practice with explicit and timely feedback
Training Teachers

• Detailed “how to” explanations (Feldon et al., 2010; Tofel-Grehl & Feldon, 2013)

\[ X^2 = 10.47, \ p=0.001 \]
“How to”: Cognitive Task Analysis

- Outline and sequence tasks as performed on the job
- Describe contexts, cues, actions, and decisions
- Collect information about equipment, standards, difficulty for novices, and reasons
- Identify conceptual knowledge required
- Collect field problems for demo, practice, testing
- Correct and verify accuracy of the results
Training Teachers

• Detailed “how to” explanations
  – Cognitive task analysis

• Guided practice with specific and timely feedback
  – Microteaching (Metcalf et al., 1996)

Hattie (2011)
Microteaching Cycle: Practice and Feedback

- Plan
- Teach
- Feedback
- Re-Plan
- Re-Teach
- Re-Feedback
Microteaching: Deepening Complexity
THEN Student Teaching
Our Challenge
Making training decisions based on science, not tradition
Thank you!

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