Teaching Computing as Science in a Research Experience

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Overview

• Research Training: Benefits and Reality
• Computing as a Discipline
• Experience Gap
• Our Approach
• Results
# Research Training

## Method
- Holz et al. [ITiCSE '07]
- Witten & Bell [SIGCSE '93]
- Fekete [SIGCSE '96]
- Ward [J. CSC '04]
- Quade [ITiCSE '04]
- Shaffer [SIGCSE Bull. '06]
- Havill & Ludwig [SIGCSE '07]
- Koppelman et al. [ITiCSE '11]

## Experience

### Integrated
- Reed et al. [SIGCSE '00]
- Hadfield & Schweitzer [ICFE '09]

### Capstone
- Schneider [SIGCSE Bull. '02]
- Walker & Slotterbeck [J. CSC '06]
- Koppelman et al. [ITiCSE '11]

### Apprenticeship
- Bernat et al. [ITiCSE '00]
- Wenderholm [SIGCSE Bull. '04]
- Koeller [J. CSC '05]
- Peckham et al. [SIGCSE '07]
- Dahlberg [SIGCSE '08]
Benefits and Reality

• **Survey of Undergraduate Research Experiences**
  
  – Enhance educational experiences
  – Attract students to research careers
  – Help retain minority students

• **CS experiences highly variable**
  
  – Depends heavily on mentor, project structure
  – “Less likely to participate in the ‘culture of research’”

• **Mixed agreement on structure**
  
  – Requires literature search and presentation: 90%
  – Requires “scientific method” (62%) or “formal process” (67%)
Computing as a Discipline

Theory
- Definition
- Theorem
- Proof
- Interpretation

Design
- Requirements
- Specifications
- Implementation
- Testing

Abstraction
- Hypothesize
- Model and predict
- Experiment
- Analyze
Computing as a Science

- Sciences of the Artificial [Simon '69]
- Computing is a Natural Science [Denning '07]
- Empirical Methods for AI [Cohen '95]

**Ergalics**: Uncovering general theories/laws governing the behavior of computational tools and computation itself. [Snodgrass '10]
Survey of Research Experiences

41 Baccalaureate colleges
2009-2013, n ≤ 6245
I feel that my supervisor was ___ as a teacher and mentor

Comparison to expectations

Overall sense of satisfaction

$P_{\text{STEM}>\text{CS}} = 0.565 \ (p<.0001)$

$P_{\text{STEM}>\text{CS}} = 0.548 \ (p<.005)$

$P_{\text{STEM}>\text{CS}} = 0.552 \ (p<.001)$
## Graduate Education Plans

<table>
<thead>
<tr>
<th></th>
<th>CS</th>
<th>STEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interest before</td>
<td>62%</td>
<td>91%</td>
</tr>
<tr>
<td>Interest gained</td>
<td>29%</td>
<td>57%</td>
</tr>
<tr>
<td>Interest lost</td>
<td>2.2%</td>
<td>1.1%</td>
</tr>
</tbody>
</table>
Benefits / Learning Gains

Understanding the research process
Tolerance for obstacles faced in the research process
Learning laboratory techniques
Understanding how scientists work on real problems
Readiness for more demanding research
Ability to analyze data and other information
Learning to work independently
Skill in interpretation of results
Ability to integrate theory and practice
Understanding how knowledge is constructed
Ability to read and understand primary literature
Becoming part of a learning community
Understanding science
Understanding that scientific assertions require supporting evidence
Understanding how scientists think
Self-confidence
Skill in how to give an effective oral presentation
Clarification of a career path
Confidence in my potential as a teacher
Learning ethical conduct
Skill in science writing

95% CI

STEM
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95% CI  ♦ CS  • STEM

Small  Moderate Gain  Large
Benefits / Learning Gains

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95% CI  ⚫ STEM>CS
Our Approach

• Integrate methods, experience
  – Situated learning
  – Legitimate peripheral participation [Ben-Ari '04]

• Context
  – Full time, 10 weeks, summer
  – Stipend, four credits (one class)

• Emphasize empirical philosophy alongside research mechanics
Curriculum

Wk. Discussion Writing Wk.
1 Computing as science
   Reproducible research
   Selecting projects
   Scientific activities
2 Research literature Research description
3 Challenges of science Assessment of current knowledge
4 Exploratory analysis Data and behavioral exploration
5 Causality and inference Research proposal
   Hypotheses and falsifiability
6 Experiments

Lectures dx.doi.org/11084/10002
Assignments dx.doi.org/11084/10000
Initial questions for ‘strong inference’

- Ontology — What is the task, system, and environment? What are the relevant entities, relations, and variables?
- Behavior — What sort of behaviors does the system exhibit when performing these tasks in these environments?
- Theory — What general theoretical frameworks exist now to predict, explain, and control this behavior?
- Hypotheses — What hypotheses could you form based on those theories? What type of hypotheses are these? Can you push yourself higher on the ontological ladder?
- Falsifiability — How falsifiable are these hypotheses? How could they be sharpened to be more falsifiable?
- Multiple hypotheses — Can you devise additional hypotheses that address the same behavior?
Regular Activities

• Daily email summary to group
• Monday milestones: team planning
• Weekly review: individual reflection
• Scholarly community: Weekly dept. presentation
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95% CI  ♦ CS  ♦ STEM

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95% CI  ♦  CS  ■  JW  ♦  STEM

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* p < .05
** p < .01
*** p < .005
**** p < .001

95% CI  • STEM>CS  □ JW>CS
Triangulation

• Not mentor:  No differences on SURE mentor question
• Not institution:  SURE benefits over other CS REUs at Grinnell
• Several student co-authored publications
• Half pursued some graduate education
Conclusions

• CS students rate research experiences lower than STEM students
• Emphasizing computing as science may help narrow the gap

[Denning et al.]

KEEP CONNECTED • KEEP COMMITTED
KEEP COMPUTING AS SCIENCE

MIND THE GAP