Enhancing our Understanding of Learner-Centered Teaching through the Scholarship of Teaching and Learning

6th Annual Scholarship of Teaching and Learning Conference at Maryville University

Gintaras K. Duda
October 11, 2014
Active Learning

• Terry Doyle gave us the cognitive science evidence for learner-centered teaching

• Where do we go from here?
• Which methods work or are more effective?
• Which don’t work for my students?
• How do we know?
My Background

- I am a theoretical particle physicist
- Came to SoTL (PER) as a junior faculty member
- Huge roadblocks: no experience with
  1. How educational research is conducted
  2. Quantitative or qualitative analysis
  3. Weak background in statistics
What is SoTL?

• SoTL can have many definitions that vary wildly

• To me SoTL is all about:
  1) Approaching teaching in a systematic way using research methodology
  2) Investigating student learning by conducting research-like experiments in the classroom
  3) Using serious data analysis
  4) Feeding the results back into the classroom
  5) Publishing the results
What is SoTL …

SoTL, according to Lee Shulman, must have three elements:
1) it should be public
2) subject to peer review and critique
3) accessible for exchange and use

- No different than any other form of scholarship!
- Teaching serious scholarship
A “Problem” from Randy Bass

• “In scholarship and research, having a `problem’ is at the heart of the investigative process.”

• How would a colleague react when asked about a “problem” in their teaching?

Randy Bass, Georgetown University

“Changing the status of the problem in teaching from terminal remediation to ongoing investigation is precisely what the movement for a scholarship of teaching is all about.”

Why DBER?

• DBER = Disciplinary-Based Educational Research

1. Need disciplinary expertise
2. Need access to students in your discipline
3. Audience is colleagues in your discipline
Areas of SoTL interest

- Student Attitudes and how attitudes affect learning
- Realism in physics
- Problem-Based Learning in upper division courses
- Student epistemologies
- How students use the internet to learn physics
- Reflection in science courses
Physics Education Research - Influences

“If I have seen further it is by standing on the shoulders of Giants.” – Isaac Newton
What do we know about (physics) students?

Many (if not most) students:

- develop weak **qualitative** understanding of concepts
  - don’t use qualitative analysis in problem solving
  - can’t reason “physically”

- lack a **“functional”** understanding of concepts

But some students learn efficiently …

- Highly successful students are “active learners”
  - they continuously probe their own understanding
  - Identify areas of confusion and confront them

- Majority of students can’t do this
  - Don’t know which questions to ask
  - Need help from instructors

Students and instructors see the same material in very different terms.

<table>
<thead>
<tr>
<th>Novice</th>
<th>Expert</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pieces</td>
<td>← structure → Coherence</td>
</tr>
<tr>
<td>Formulas</td>
<td>← content → Concepts &amp;</td>
</tr>
<tr>
<td>plug &amp; chug</td>
<td>Problem Solving</td>
</tr>
<tr>
<td>By Authority</td>
<td>← learning → Independent</td>
</tr>
<tr>
<td></td>
<td>(experiment)</td>
</tr>
</tbody>
</table>
Concrete vs. Abstract

Students see these as two separate problems
Even at Harvard …

- Eric Mazur found his students could to problems like this
- But not like this

Find the currents flowing in each branch of the circuit

What happens to the brightness of the three bulbs, A, B, and C, when the switch S is closed.
Key Results from Research in Education and Cognition

1) Knowledge is associative/linked to prior models and cognitive structures

2) Learning is productive/constructive – learning requires mental effort

3) The cognitive response is context dependent

4) Most people require some social interaction to learn deeply and effectively.

Ed Prather and Tim Slater, AAS Workshop
Is this education?
Is this Education?
What students already know influences how students learn!

- Concept of phenomenological primitives or p-prims¹
  1. Strongly held, stable cognitive structures
  2. Differ from expert conceptions
  3. Affect how students understand nature
  4. Must be overcome

A Private Universe

- Graduates at Harvard asked “Why is the Earth warmer during the summer than the winter?”


http://musical-costumers.blogspot.com
Active Learning

- I want to focus on one key result:

  “Learning is productive/constructive and requires mental effort”

- Does the evidence support this statement?

- How can SoTL support the active-learning classroom?
Dean Zollman on Active Learning

• Dean tells a great story about visiting the department with his daughter¹

¹D. Zollman, American Journal of Physics 64, 114 (1996)
The Evidence

- Richard Hake\(^1\) conducted a study of 62 courses with 6,542 students nation-wide
  - Looked at Force Concept Inventory Scores

- Split the sample into:
  - 14 Traditional Courses: N=2084
  - 48 Interactive Engagement Courses: N=4458

Interactive engagement leads to measurably higher normalized gains on standard assessment exams.

More recently¹

- Meta-analysis of 225 studies in STEM on active learning by Scott Freeman et al. in PNAS

1. Does active learning boost exam scores?
2. Does it lower failure rates?

¹http://www.pnas.org/content/111/23/8410
Examples: My Work in SoTL/PER
Student Attitudes and Epistemologies

- Educational research shows that student attitudes affect their learning\(^1,2\)
- Epistemologies are also important
  – “set of views about the nature of knowledge, knowing, and learning in physics”\(^3\)

From the MPEX Survey

- MPEX\(^1\) survey probes “student attitudes, beliefs, and assumptions about physics”

```
In all cases, the result of instruction on the overall survey was an *increase* in unfavorable responses and a decrease in favorable responses ... *Thus instruction produced an average deterioration rather than an improvement of student expectations.*
```

Students learn about how friction works in the real-world by reading about how Geckos scale walls.

Microscopic attraction!

http://generalphysics211.blogspot.com/
**Effect on Attitudes**

![A-D plot for Semester II (spring 2006) for question 19: "Physics is not useful in my everyday life."](image)

Figure 4: A-D plot for Semester II (spring 2006) for question 19: "Physics is not useful in my everyday life."

The “Gender Gap”: FMCE Gains

<table>
<thead>
<tr>
<th>Students</th>
<th>Normalized Gain</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control Group</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Males (n=82)</td>
<td>0.67</td>
<td>&lt; 0.05</td>
</tr>
<tr>
<td>Females (n=63)</td>
<td>0.50</td>
<td>(significant)</td>
</tr>
<tr>
<td>Experimental Group</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Males (n=50)</td>
<td>0.63</td>
<td>0.165</td>
</tr>
<tr>
<td>Females (n=96)</td>
<td>0.56</td>
<td>(not significant)</td>
</tr>
</tbody>
</table>

Experimental group read and reviewed a course blog which focused on applications of physics

What next? PBL and SDL + SRL

• Self-Regulated Learning
  – “The extent to which learners are metacognitively, motivationally, and behaviorally active in their own learning process.”

• Self-Directed Learning
  – “A student’s preparedness to engage in learning activities defined by the student, rather than by the teacher.”

Project-based Learning in a Nutshell

1. Learning initiated by a project/problem.
2. Projects are complex and based on the real-world.
3. All needed information is not given.
4. Students identify, find, and use appropriate resources.
5. Students work in rotating teams.
6. Learning is active and connected.

From U. Delaware Institute for Transforming Undergrad. Educ.
Project-based Learning Outcomes

1. Think critically and solve real-world problems
2. Find, evaluate, and use appropriate sources
3. Work cooperatively in small groups/teams
4. Demonstrate effective communication skills
5. Become active and reflective learners: SDL + SRL

**Bottom line:** Students do physics as physics is done in the “real world”
• Barbara Dutch and collaborators pioneered work in using PBL in physics\textsuperscript{1,2} – \textbf{BUT}, just introductory physics courses

• How does this work in upper division classes?

Example: Mathematical Physics

• Sophomore/junior level course

Module Learning Goals (vague):
1. Students will construct complex models using Differential Equations
2. Students will solve non-linear (complicated) Differential Equations
3. Students will learn how to solve differential equations numerically
Modeling the Zombie Apocalypse
The Assignment

1. Pick a zombie outbreak scenario as depicted in popular media or literature

2. Model an outbreak and solve for:
   i. The uninfected human population as a function of time
   ii. The zombie population as a function of time

3. Justify and explore the consequences of the model
Chapter 4

When Zombies Attack!: Mathematical Modelling of an Outbreak of Zombie Infection

Philip Munz\textsuperscript{1}, Ioan Hudea\textsuperscript{1}, Joe Imad\textsuperscript{2}, Robert J. Smith\textsuperscript{2,3,6}

\textsuperscript{1}School of Mathematics and Statistics, Carleton University, 1125 Colonel By Drive, Ottawa, ON K1S 5B6, Canada
\textsuperscript{2}Department of Mathematics, The University of Ottawa, 585 King Edward Ave, Ottawa ON K1N 6N5, Canada
\textsuperscript{3}Department of Mathematics and Faculty of Medicine, The University of Ottawa, 585 King Edward Ave, Ottawa ON K1N 6N5, Canada

Basic Model Results

Human population is wiped out
Increasing Killing Parameter

Humans survive and fight back the zombie outbreak.
The currency tracking project Wheresgeorge.com used to model the spread of an infectious disease\textsuperscript{1}:

## Did it work?¹

<table>
<thead>
<tr>
<th>Survey Question</th>
<th>Strongly Agree</th>
<th>Weakly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>The Zombie PBL project made the class more interesting to me</td>
<td>63.6%</td>
<td>36.4%</td>
</tr>
<tr>
<td>I learned more from the PBL project than I would have from traditional lecture and problem sets</td>
<td>36.4%</td>
<td>54.5%</td>
</tr>
<tr>
<td>I am more confident in my mathematical modeling skills due to the Zombie PBL project</td>
<td>9.1%</td>
<td>54.5%</td>
</tr>
</tbody>
</table>

Student Comment: “I thought the project was a great way to cover the material. My Maple skills improved dramatically. I’m now very comfortable with solving DEs numerically. I don’t think that I could say that if we had just done a simple example in class.”

What did I learn?

1. Students though it would work
2. Students wanted scaffolding
3. Students needed help finding resources
2011- today: Project-based Quantum Mechanics

- Junior/Senior level, one-semester quantum mechanics course
- 6-10 students per semester since 2011
- Most difficult class in the major
Course Structure

• **No lectures!**

• Project introduces and motivates the learning in each module
  – Module 1: Why is Energy Quantized?
  – Module 2: How do systems evolve in time?
  – Module 3: What is spin?
  – Module 4: What happens in 3D?

• Weekly HELL Packets
  – Provide scaffolding
No lectures?

Students are expected to set their own pace, utilize class time effectively, and plan for due dates.
Lecture Tutorials

• 1-3 lecture tutorials per week
• Guided derivation/exploration of the material
• Revision and addition to basic set of tutorials by Todd Timberlake¹

• Learning Objectives are clearly spelled out for students in each tutorial

¹http://facultyweb.berry.edu/ttimberlake/active_quantum/
Lecture Tutorial: The Finite Square Well

In this tutorial we will investigate the energy eigenvalues and eigenstates for bound states in a finite square well. This system is a bit more realistic than the particle in a box model (infinite well) and we’ll discover that it has some interesting and unexpected properties. Additionally we’ll be introduced to what role symmetry can play in quantum systems.

The learning objectives for this tutorial are:

1. To solve the 1D time independent Schrodinger Equation for the finite square well potential in all regions.
2. To observe in another context how energy quantization arises as a result of boundary conditions.
3. To find allowed energies through graphical solutions of transcendental equations.
4. To explore and calculate the number of bound states that a given finite well can support.
5. To discover and quantify the role of symmetry in 1D potential problems in quantum mechanics.

Let’s begin:

The finite square well is a system defined by the potential function

\[ V(x) = \begin{cases} -V_0, & |x| < a \\ 0, & |x| \geq a, \end{cases} \]

which is symmetric about \( x = 0 \).
Metacognitive Self-Monitoring

Finite Well Tutorial Self-Assessment

Please rate yourself on the learning objectives of the tutorial using the scale provided. Be honest and identify areas in which you are still struggling!

<table>
<thead>
<tr>
<th>Objective (Students will be able ...)</th>
<th>Did not Meet Objective</th>
<th>Need more help to meet objective</th>
<th>Met Objective</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. To solve the 1D time independent Schrodinger Equation for the finite square well potential in all regions.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. To demonstrate in another context how energy quantization arises as a result of boundary conditions.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. To find allowed energies through graphical solutions of transcendental equations.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. To explore and calculate the number of bound states that a given finite well can support.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. To discover and quantify the role of symmetry in 1D potential problems in quantum mechanics.</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

After completing the tutorial, where are you still struggling? What are you still confused about and what questions do you have?
α-decay of Uranium by quantum tunneling\textsuperscript{1,2}

\textsuperscript{1}G. Gamow, \textit{Z. Physik} \textbf{51}, 204 (1928)
Student Reflections and Assessment

- Student reflection is a key element of the course
- End of project reflections
- Goal setting (pre) and final reflection (post)
- QMAT\textsuperscript{1} is used as a midterm diagnostic
- QMS\textsuperscript{2} survey given pre and post
- CLASS\textsuperscript{3} is given pre and post

\textsuperscript{1}S. Goldhaber et al., 2009 PERC Proceedings
\textsuperscript{3}http://www.colorado.edu/sei/class/
Reflections

- Reflections were analyzed using a framework from the literature\(^1\).
- Categories
  1. Technical
  2. In and On Action
  3. Personal
  4. Deliberative
  5. Critical
- Evidence for epistemological growth!

Assessment Results

- Performance on common final exam
- QMAT scores
- QMS scores
- Other important elements – more difficult to quantify:
  - Teaming Abilities
  - Scientific Writing
  - Self-directed Learning and Self-Regulated Learning
  - Shift in motivation
Why worry about epistemologies?

- In physics research is extremely important
  - Part of our professional persona
  - Should be promoted early in the career

- Large “gap” between courses and research
  - Retention
  - Transition to graduate school
Epistemologies in Physics

- Within physics, David Hammer\(^1\) established a set of epistemological dimensions (from student interviews and observations).

1. **Novice**
   - Formulas
   - Pieces
   - Authority
   - Innate

2. **Expert-like**
   - Concepts
   - Coherence
   - Independence
   - Effort

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Evidence Gathering

• Surveyed all graduates of the quantum mechanics course from 2011-2013
  – N=15

• Conducted multiple focus groups

• Used student reflections
  – Evidence of epistemological shifts
### TABLE 1. Student Responses to selected Likert-Scale survey questions (N=15). The question reads “Project-based pedagogy used in this class contributed to my growth as a student/physicist in the following areas:"

<table>
<thead>
<tr>
<th>Survey Question</th>
<th>Strongly Agree</th>
<th>Agree</th>
<th>Neutral</th>
</tr>
</thead>
<tbody>
<tr>
<td>Content Mastery</td>
<td>33.3%</td>
<td>40.0%</td>
<td>26.7%</td>
</tr>
<tr>
<td>Scientific Writing</td>
<td>53.4%</td>
<td>33.3%</td>
<td>13.3%</td>
</tr>
<tr>
<td>Sense of professionalism</td>
<td>46.7%</td>
<td>26.7%</td>
<td>26.6%</td>
</tr>
<tr>
<td>Taking charge of my own learning</td>
<td>46.7%</td>
<td>33.3%</td>
<td>20.0%</td>
</tr>
<tr>
<td>Being an Active Learner</td>
<td>46.7%</td>
<td>40.0%</td>
<td>13.3%</td>
</tr>
<tr>
<td>See real-world connections</td>
<td>46.7%</td>
<td>33.3%</td>
<td>20.0%</td>
</tr>
<tr>
<td>More interested in QM</td>
<td>53.3%</td>
<td>13.3%</td>
<td>33.3%</td>
</tr>
<tr>
<td>More confidence to do physics</td>
<td>46.7%</td>
<td>33.3%</td>
<td>13.3%</td>
</tr>
</tbody>
</table>

### TABLE 2. Student Responses to selected Likert-Scale survey questions (N=15) that dealt with reflection or changes in epistemologies.

<table>
<thead>
<tr>
<th>Survey Question</th>
<th>Strongly Agree</th>
<th>Agree</th>
<th>Neutral</th>
</tr>
</thead>
<tbody>
<tr>
<td>I felt I grew as a physicist</td>
<td>46.6%</td>
<td>40%</td>
<td></td>
</tr>
<tr>
<td>More prepared to learn on my own</td>
<td>33.3%</td>
<td>46.7%</td>
<td>20.0%</td>
</tr>
<tr>
<td>More able to tackle complicated, real-life problems</td>
<td>40.0%</td>
<td>40.0%</td>
<td>20.0%</td>
</tr>
<tr>
<td>Should do more reflection in physics courses</td>
<td>26.7%</td>
<td>33.3%</td>
<td>13.3%</td>
</tr>
</tbody>
</table>

\(^{1}\text{To appear in the 2014 Physics Education Research Conference Proceedings}\)
“Out of the class that’s what I got mainly out of it. At first everything seems a bit free for students, and it forces you to see what’s out there to solve a problem, right? And, uh, I think it actually helped me in my own research not just in the research itself but how to acquire data and how to look for data and that was actually really helpful. The idea of going in blind into a project - you don’t know what you’re doing and you don’t master the concepts first - was really important as part of the experience. Because whenever you’re actually doing innovative research you’re more or less blind - the material you’re doing is not mastered and not understood.”
"I know that was one of the difficulties I had with the course - um - was the sort of the lack of lecture-based instruction, because I feel like I’ve invested a lot into getting good at learning in a lecture-based environment. Um, so I felt like there was a tension at least for me between this class as learning in terms of the traditional educational path - learning the topic - versus as a tool for professional development and to get better at doing the science rather than just learning the material. For me this was the primary struggle I had for the course - trying to rectify the idea of this as making me a better scientist and physicist versus feeling like I was floundering a bit for the course material itself."
PBL Quantum: What have I learned?

• PBL offers a way to engage students with real-world problems in a 100% active environment
• Physics is done the way physics is practiced
• Highly motivated students emerge
• Reflections give evidence of student epistemological growth and increases in intrinsic motivation

http://physicsweb.creighton.edu/pbl_quantum
Next Steps

- Developing and validating a SRL/SDL inventory
- Studying reflection in multiple project-based courses
  - Physics, pre-engineering, energy science, etc.
- Look for evidence of epistemological growth
  - PBL vs. non-PBL courses
Conclusions

• SoTL/PER (or DBER) offers us a way to **TEST** different active learning strategies

• Would you accept a result in your scholarship without sufficient evidence?

• Why do so in teaching then?
My SoTL advice

• Plan a throw-away semester in any SoTL study
  – “trial” period to tinker with your study design
  – Flexibility to alter your study design when you find it doesn’t work
• Involving students in SoTL work can be very effective
• Try to publish in discipline specific journals
• When in doubt, ask your students!
Good References

- The FLAG: Field-Tested Learning Assessment Guide
  - [www.flaguide.org](http://www.flaguide.org)
  - Contains “broadly applicable, self-contained modula classroom assessment techniques (CATs) and discipline-specific tools for STEM instructors”
John Creswell’s books (and courses) have been highly recommended to me