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Why Can't They Solve It? Using Protocol Analysis to Unlock Problem Solving Mysteries

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Why can’t they solve it?
Using Protocol Analysis to unlock problem solving mysteries

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Two common SOTL questions

- A “What works” question (Intervention)
  “Whether students in College Algebra are learning more, when supported by a online homework, tutorial, and assessment system than they would in traditional versions of the course”

- A “What is” question (As is)
  “Why do students have difficulty when doing related rates questions”

Ref: “Approaching the scholarship of teaching and learning”-Pat Hutchings
http://www.carnegiefoundation.org/elibrary/approaching-scholarship-teaching-and-learning
Ways of gathering SOTL Evidence

- Common Formats
  - Class Assignments and Inventories
  - Focus Groups/Interviews
  - Protocol Analysis/Think Alouds
  - Observation
Our SOTL question

- “Why do Calculus II students in general, have difficulty with “Work” problems?
  (A “What is” problem)

We decided to use think alouds as a measure.
What is a “Think aloud protocol”? 

- The basic idea behind a think aloud is that if a subject can be trained to think out loud while completing a defined task, then the introspections can be recorded and analyzed by researchers to determine what cognitive processes were employed to deal with the problem (Lendol Calder and Sarah-Eva Carlson)

- Originated by Karl Duncker(1945) who described it as a way to understand the development of thought of a subject
- Ericsson and Simon (1993) considered Think alouds as a valid process for gathering evidence when researching cognitive process.
- Schonefield (1985) has used protocol analysis to study mathematical problem solving.
- Clement (1982) conducted a think aloud to determine how misconceptions arise when students do word problems that lead to equations of type $ax=by$
What did we do? The process

- Prepared four problems on “work” (Selected 3 problems for the study)

- Selected six students of varying abilities

- Each student had 1-1 session with the instructor lasting about an hour

- Sessions were video recorded
Problem List

1. Find the work done in lifting a box weighing 10 lb through a distance of 5 ft?

2. A circular swimming pool has a diameter of 20 ft, the sides are 5 ft high, and the depth of the water is 4 ft. How much work is required to pump all of the water out over the side? (Use the fact that water weighs 62.5 lb/ft³.)

3. A reservoir shaped like a right circular cone, point down, 20 ft across the top and 8 ft deep, is full of water. How much work does it take to pump the water to a level 6 ft above the top?
During the Sessions

- Students were first trained to think aloud

- Solve the problems and verbalize all thoughts that came to mind while solving the problems

- The instructor only prompted them to keep talking and voicing their thoughts
After the recordings

- **Recordings were transcribed**
- To help translate the thinking process more accurately, **screen shots** of the problems were also taken
- The transcripts needed to be coded (Van Someren, 1994)
Activity

- The leaf shaped region is made up of quarter circles. What is its area?

- Student think aloud video
Poyla’s four step process for problem solving

As part of his work on problem solving, Polya developed a four-step problem-solving process similar to the following:

- **Understanding the Problem**
- **Devising a Plan**
- **Carrying out the Plan**
- **Looking Back**
Created Coding Rubric using Pólya’s problem solving steps as a guide (Code Sheet)

Click to see Sample coded problem
Analysis

Highlighted the codes which represent thought patterns of a professional mathematician while problem solving and rated them.

Professional Mathematician solving the same problem

- Strategy
- Mathematical Argument
- Logical Inference
“Rated” Scripts (Likert type scale)

<table>
<thead>
<tr>
<th>Student</th>
<th>Strategy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Student #1</td>
<td>1</td>
</tr>
<tr>
<td>Student #2</td>
<td>4</td>
</tr>
<tr>
<td>Student #3</td>
<td>1</td>
</tr>
<tr>
<td>Student #4</td>
<td>5</td>
</tr>
<tr>
<td>Student #5</td>
<td>3</td>
</tr>
<tr>
<td>Student #6</td>
<td>5</td>
</tr>
</tbody>
</table>

**1**
Novice problem solver

**5**
Expert professional mathematician
A closer analysis

A closer look revealed that the differences in the ratings lay mainly in the strategy involved in setting up the work required for the generic ($i^{th}$) slice, henceforth referred to as the subproblem.

We carefully analyzed the vocalizations of each student around the area where they set up the subproblem.
The problem

A circular swimming pool has a diameter of 20 ft, the sides are 5 ft high, and the depth of the water is 4 ft. How much work is required to pump all of the water out over the side? (Use the fact that water weighs 62.5 lb/ft³.)
Solution steps for the problem

- Work = Force x Distance

- Total Work \( \approx \sum \text{little work} \)
  \( \approx \sum W_i \)

- \( W_i = \) Work for the \( i^{th} \) slice

- Total Work \( W = \int_{a}^{b} W_i \)
Protocol Analysis of Student 5
Yeah, I’ll make the $x$ is equal to four, I guess… and then… I’ll make a strip here… (St)
Subject draws a horizontal line, but the view is still obstructed.
So it’ll be a distance of $x_i$… for that layer… (St, SV)
Subject moves his hand; the picture looks like this:

![Diagram]

M: $4 \text{ ft}$

???
Subject writes “$V=$”, then pauses and scratches head. Umm… delta $x$…
Subject writes “$\Delta x$” after “$V=$”.

So then the volume would be… umm… times umm… 20 feet, I suppose… )” (MA_I)
Subject writes “(20)”.

The Equation now reads “$V_i=\Delta x(20)$”
That would be the volume $V_i$ of the $i$th layer... (SV)

And... so then the... force would be... um... 20 times delta $x$... times... 62.5 [Questioning tone] (I_P, MA)

Subject writes as he speaks. However, his hand once again obstructs the view of his drawing.

And then... umm... let's see... (X)

Subject rolls pencil between his fingers as he is thinking, sometimes waving it back and forth.

To find the work, you multiply that times the distance...(St)

so 20 times delta $x$, times 62.5... times the distance, (I_P) which is... $x_i$ plus 1

Subject writes as he speaks. It is still obstructed.

Subject moves his hand. His writing is hard to read, but it looks as though he has written “$F = 200 \Delta x \times 62.5$”, and below that, he has written “$W=200 \Delta x \times 62.5 \ (x_i+1)$”.

Hmmm... The distance to pump out... this $i$th layer would be... the $x_i$ plus this one... so $x_i$ plus one.
## Common Observations

<table>
<thead>
<tr>
<th></th>
<th>Seems to understand that the sub problem has to be done first</th>
<th>Seems to remember the procedure how the sub problem can be setup</th>
<th>Seems to indicate an understanding the objective of the sub problem</th>
<th>Seems to indicate a knowledge overall philosophy of the sub problem</th>
<th>A gap in the math tool kit, or confusion with another concept</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>S1</strong></td>
<td>Yes</td>
<td>Little</td>
<td>No</td>
<td>No</td>
<td>Significant</td>
</tr>
<tr>
<td><strong>S2</strong></td>
<td>Yes</td>
<td>Almost all</td>
<td>May be</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td><strong>S3</strong></td>
<td>Yes</td>
<td>Little</td>
<td>No</td>
<td>No</td>
<td>Significant</td>
</tr>
<tr>
<td><strong>S4</strong></td>
<td>Yes</td>
<td>Almost all</td>
<td>Yes</td>
<td>Maybe</td>
<td>Small but critical</td>
</tr>
<tr>
<td><strong>S5</strong></td>
<td>Yes</td>
<td>Quite a bit</td>
<td>May be</td>
<td>No</td>
<td>Significant</td>
</tr>
<tr>
<td><strong>S6</strong></td>
<td>Yes</td>
<td>Almost all</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
</tbody>
</table>
Conclusions

- Majority of the students do not seem to know the objective behind setting up the sub problem. (A possible intervention is to make students set up sub problems for all the integration applications and get them to “discover” the formulae) http://www.uwlax.edu/sotl/lsp/Final%20Reports/LS%20Arc%20Length%20Final%20Report.pdf.

- Most students seem to tend to “memorize” the procedure involved in setting up the sub problem.

- Most students seem to have shortcomings in recalling details from their algebra/geometry toolkit.

- The analysis can benefit through moderator asking one or two questions at critical points of the think aloud (Like “Why are you considering a slice of water first?”)
Possible “what works” SOTL projects

- “Will asking students to write down focal strategy for credit at the beginning of the problem, improve the problem solving ability among students?”
- “Work” is the first section in integration applications where is no “ready made” formulae. This could be one reason for the lack of practice setting up the subproblem. A possible intervention would be to “subproblem” setup activities for other topics too.
- To help students achieve better understanding of the problem (Polya’s first step), embed a “hand-on” activity to get a feel of what “work” is.