Using the SOLO Taxonomy to Understand Subgoal Labels Effect in CS1

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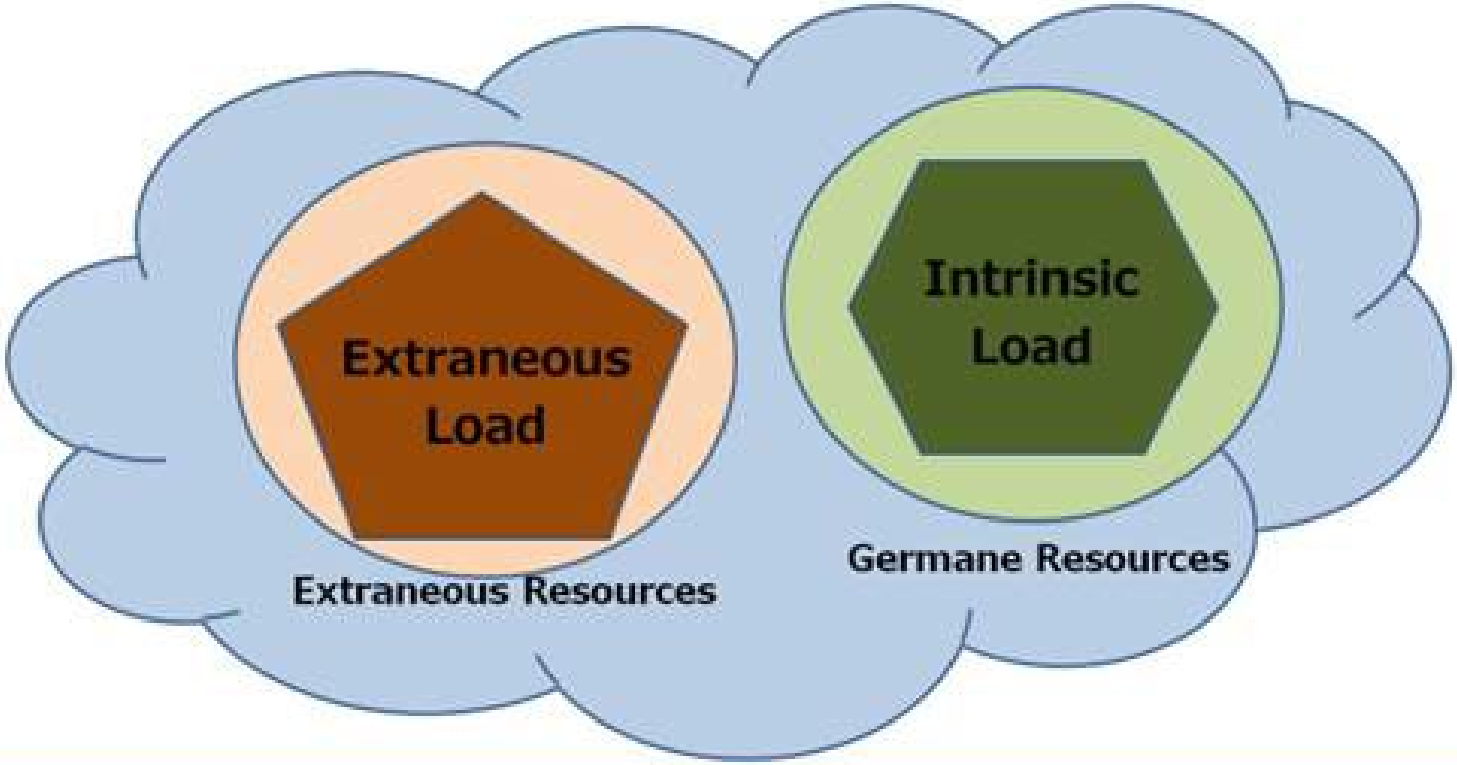
How did we get here?

Subgoals

Working Memory & CLT

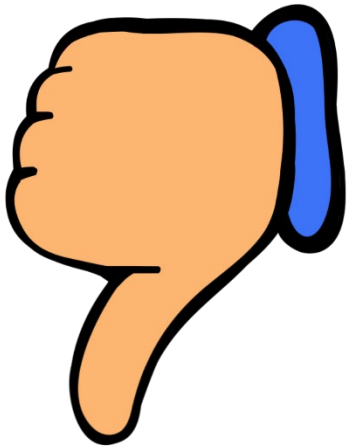


Worked Examples

Step-by-step demonstration of how to perform a task or how to solve a problem

http://clipart-library.com/thumbs-up.html

Must include details specific to the problem -> can be hard to abstract general procedure



http://clipart-library.com/thumbs-down.html

Subgoal Labels

- Shared functional features of working examples helping learner to organize the information (Cantrambone, 1998)

http://clipart-library.com/thumbs-up.html

How did we get here?

Subgoals in Programming

Subgoal Labels Effectiveness

- Subgoal labeled worked examples improve performance for
  - Block-based programming

    Margulieux, Guzdial, & Catrambone, 2012; Margulieux & Catrambone, 2016; Margulieux, Catrambone, & Guzdial 2016
  - Text-based programming

    Morrison, Margulieux, & Guzdial, 2015; Morrison, Margulieux, Ericson, & Guzdial, 2016; Morrison, Decker, & Margulieux, 2016
  - K-12 Teachers

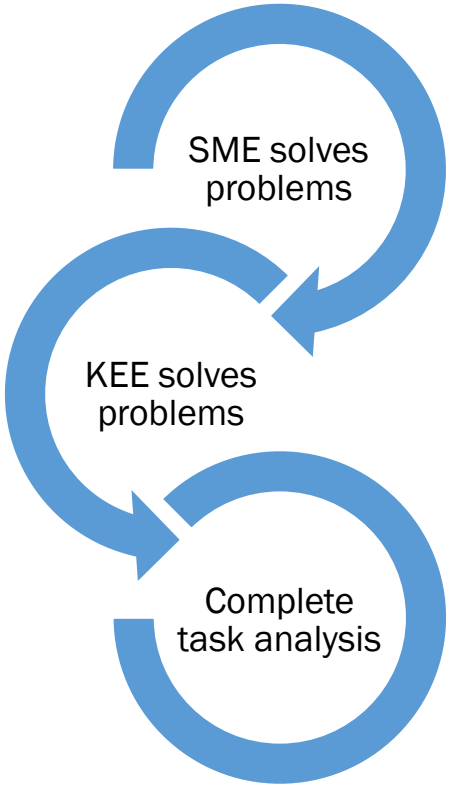
    Margulieux, Catrambone, & Guzdial, 2013

Current Study

Subgoals throughout CS1

Task Analysis by Problem Solving

- TAPS protocol
  - Subject matter expert (SME)
  - Knowledge extraction expert (KEE)
  - Focus on problem solving, not teaching
  - Identify areas of tacit knowledge



Margulieux, L. E., Morrison, B. B., & Decker, A. (ITiCSE 2019)

Topics with Subgoals for CS1

- Expressions
- Selection statements
- Loops
- Arrays
- Object instantiation and method calls
- Writing classes

Evaluating and Writing Selection Statements

Evaluate selection statement

1. Diagram which statements go together
2. For if statement, determine whether expression is true or false
3. If true – follow true branch, if false –follow else branch or do nothing if no else branch

Write selection statement

1. Define how many mutually exclusive paths are needed
2. Order from most restrictive/selective group to least restrictive
3. Write if statement with Boolean expression
4. Follow with true bracket including action
5. Follow with else bracket
6. Repeat until all groups and actions are accounted for

Pilot

- Compare groups at UNO (*N* = 307) Fall 2018 semester [August-December 2018]
  - Received traditional worked examples and practice problems
  - Received subgoal labeled worked examples and practice problems
- Everything else was the same
  - Qualifications of instructors
  - TAs
  - Quizzes (collected data)
  - Exams (collected data)
  - Labs
  - Assignments

Previous Results (ITiCSE 2019)

Quizzes

Total score higher for subgoal group, $d = 0.42$

Average score higher for subgoal group, $d = 0.44$

Exams

Total score higher for subgoal group, $d = 0.26$

Average score not different for subgoal group, $d = 0.20$

Explain in Plain English

- Question on Quiz 4, 8, 10, 12 of the semester

Quiz 1 example question:

For the problem below, explain the general steps that you would take to solve the problem. You do not need to solve the problem. Instead, imagine that you are describing the general steps that you would take to evaluate code like this to yourself before you learned this unit/topic/etc.

```
int alpha = 20
int eta = 5
double beta = 4.5
double gamma = 5.5
double delta = 0.5
double result = ((beta + gamma) – (++alpha * delta)) * (eta++ % alpha);
```

Quiz 4 example question:

Explain the steps that you would follow to write a method header for a class that meets these specifications:

Write a public method header that does not return anything but accepts as parameters a String and a double and an integer in that order and calculates the speed of a yellow-tailed swallow.

Note that you do not have to write the method header, just the steps that would go through to decide what to write.

SOLO Taxonomy

- Provides a framework for more consistent, qualitative evaluation of student responses to open-ended questions.
- A 2004 ITiCSE Working Group (the Leeds Group) provided the first attempt at mapping the SOLO taxonomy to computing.
  - We adopted their mapping

SOLO Mappings for this study

Category	Definition
Prestructural	Significant misconception or preconception irrelevant to programming
Unistructural	Correct grasp of some but not all aspects of the problem (i.e., educated guess)
Multistructural	Understands all parts of the problem but does not exhibit an awareness of the relationships between the parts; the answer may be correct or not
Relational	Parts of the problem are integrated into a structure; the answer may be correct or not
Extended	The response goes beyond the immediate problem and links to a broader context

Coding Process

- Responses were scored in aggregate, anonymously, no indication of whether they were in subgoal or control group.
- Three coders working concurrently
  - First 10 coded cooperatively
  - Next 10 independently and resolution
  - Continued until 20% coded by all three raters
  - Coded independently if IRR was acceptable, if not, kept going collaboratively until IRR acceptable

Results – Quiz 1 (Expressions)

84 students in the subgoal group; 75 students in the control group

	1 (Prestructural)	2 (Unistructural)	3 (Multistructural)	4 (Relational)	5 (Extended)
Subgoal Mode = 4	1 (1%)	8 (10%)	18 (21%)	43 (51%)	14 (17%)
Control Mode = 3	6 (8%)	14 (19%)	27 (36%)	25 (33%)	3 (4%)

SOLO	Description	Example
1	Nonsensical answer or answer that had no more information than the question provided	“Solve each equation.”
2	Described how to solve part of the problem, but the description was incomplete	“First I would do the things within each set of parentheses. Second, I would do the multiplication. Finally I would subtract.”
3	Described how to solve the complete problem but provided no explanation beyond the question at hand	“You need to follow the order of precedence for Java, so first you would do what is in the parentheses. In the parentheses you would do the ++ first from right to left, followed by modulus, then multiplication and division from left to right.”

SOLO	Description	Example
4	Described how to solve the problem and explained in abstract terms either how to evaluate pre- and post-increments or how to evaluate the appropriateness of data type between the variables	“First I would take the values within the parentheses and try to solve for those first. Starting with the one that has multiplication first, then modulus, and last, addition. ++Alpha would need 1 added to its value since it is a pre added value. Eta++ would add 1 to its value after solving for the result then take the modulus of eta++ % alpha.”
5	Described how to solve the problem and explained how to evaluate data type and increments for expression statements in general	“First thing I like to establish is what is an int, what is a double, and then what kind of answer do they want. We know they are looking for a decimal because it is a double. Next, go to the equation and treat it like math class using the orders of operation; PEMDAS. Starting from the beginning of that rule we have parenthesis, so we'll start by doing everything within their respected parenthesis. beta + gamma is pretty general, just add the two together. ++alpha * delta you want to add one to the variable alpha and then multiply that with delta. eta++ %alpha you will start by doing eta modular alpha and then add 1 because the ++ comes after the effected variable. Now follow order of operations.”

Data Types

- To get rating of 4 or 5, the answer must mention data types or type compatibility.
  - Subgoal group - 29% mention data types/compatibility
  - Control group – 12% mention data types/compatibility
- Determine whether the data type of expression is compatible with the data type of variable.

Conclusions

- Subgoal label group
  - Gave more complete answers, often including relational and abstract information, on three of the four quiz questions.
  - On the SOLO taxonomy, demonstrated a higher level of cognitive understanding of the underlying programming principles.
  - On one question where this was not the case (equivalent performance)
    - Question required more pieces of content knowledge
    - Subgoal labels from the SLWE did not fit the problem

Limitations

- Course instructor part of the research team
- One institution
- One semester

Next Steps

- Implement in courses delivered by instructors outside research team (2019-2020 academic year)

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