Using Subgoal Labels to Reduce Cognitive Load in Introductory Programming

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THREATS TO LEARNING
Mancinetti, Guttormsen, & Berendonk, Feb. 2019, European Journal of Internal Medicine

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Learning occurs when:

- Schema creation
- Assimilation
- Elaboration
- Accommodation
Cognitive Load Theory
10. Consider the following method.

```java
public void numberCheck(int maxNum)
{
    int typeA = 0;
    int typeB = 0;
    int typeC = 0;

    for (int k = 1; k <= maxNum; k++)
    {
        if (k % 2 == 0 && k % 5 == 0)
            typeA++;
        if (k % 2 == 0)
            typeB++;
        if (k % 5 == 0)
            typeC++;
    }

    System.out.println(typeA + " " + typeB + " " + typeC);
}
```

What is printed as a result of the call `numberCheck(50)`?

(A) 5 20 5
(B) 5 20 10
(C) 5 25 5
(D) 5 25 10
(E) 30 25 10
WORKED EXAMPLES
Algebra Worked Example

\[
50x + (-22) + 42x = -15
\]

\[
\begin{align*}
+22 & \quad +22 \\
50x + 42x &= 7 \\
(50 + 42)x &= 7 \\
92x &= 7 \\
\frac{92x}{92} &= \frac{7}{92} \\
x &= \frac{7}{92}
\end{align*}
\]


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**Worked Example for Speed, Distance, Time problem**

**Question:** A Lamborghini drives for 50 miles at its max speed of 200 mph. How fast does it do it?

**Step 1:** Refer to your formula for Distance, Speed and Time. What do you want to find out?

**Step 2:** Time = Distance / Speed
- Distance: 50 miles
- Speed: 200 mph

**Step 3:** Time = Distance / Speed
- Time = 50 / 200
- Time = 0.25 hrs

**Step 4:** 1 hr = 60 minutes
- 0.25 hrs = 0.25 \times 60
- 0.25 hrs = 15 minutes

**Step 5:** Time = 15 minutes

[https://khsbpp.wordpress.com/2017/05/22/cognitive-load-theory-every-teacher-should-know-this/](https://khsbpp.wordpress.com/2017/05/22/cognitive-load-theory-every-teacher-should-know-this/)
Worked Examples

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

Must include details specific to the problem -> can be hard to abstract general procedure
MINIMIZING THREATS THROUGH INSTRUCTIONAL DESIGN

Subgoal Learning
Subgoal Labels

Instructional explanations of the steps

\[4x - 8 = 2x + 6\]

\[+ 8 = + 8\]
\[-2x = -2x\]
\[4x - 2x = 6 + 8\]
\[2x = 14\]
\[\frac{2x}{2} = \frac{14}{2}\]
\[x = 7\]
Subgoal Learning Framework

- Subgoal Labeled Worked Examples
  - Group Individual Steps
  - Meaningfully Label Chunks
  - Highlight Structure
  - Organize Information
  - Decontextualize Example
  - Improve Transfer
  - Improve Problem Solving
Subgoal Labels

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

http://clipart-library.com/thumbs-up.html
A ball with mass 10kg on the desk is shooting at initial velocity of 10m/s. Calculate the velocity of the ball when it hits the ground.

Solution

When the ball leave from the desk, the ball is forced by weight force only. The object will keep constant velocity motion in X direction and constant acceleration motion in Y direction.

1) flight time $t$

$$h = \frac{1}{2} \times g \times t^2 \quad \Rightarrow \quad t = \sqrt{\frac{2h}{g}} = 2s$$

2) velocity in X direction

$$v_x = v_{0x} = 10m/s$$

3) velocity in Y direction

$$v_y = v_{0y} + g \times t = 0 + 10 \times 2 = 20(m/s)$$

4) total velocity

$$v = \sqrt{v_x^2 + v_y^2} = 10\sqrt{5}m/s$$
So What is a Subgoal?

▪ Individual steps => subgoals => solution

▪ A good subgoal label:
  • describes the function or the goal of each group of steps
  • should convey what the steps achieve
  • help the learner connect steps of the procedure to their purpose

▪ Action-based phrases

▪ They indicate next step in the problem-solving process
SUBGOAL: define and initialize variables
Step one: define and initialize variable to hold the collection of tips
```
tips = [15, 5.50, 6.75, 10, 12, 18.50, 11.75, 9]
```
- list containing all the tip values

Step two: define an initialize variable to hold the sum
```
tips = [15, 5.50, 6.75, 10, 12, 18.50, 11.75, 9]
tips = [15, 5.50, 6.75, 10, 12, 18.50, 11.75, 9]
sum = 0
```
- list containing all the tip values
- accumulator to hold
- sum of values
SUBGOAL LEARNING IN PROGRAMMING
Subgoal Label 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
Illuminate Tacit Knowledge

• Rub your belly
• Continue, and tap your head

• Now take 1 minute and think about how you would explain to someone:
  • How to ride a bike
  • How to tie your shoe

Automaticity

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Topics with Subgoals for CS1

- Expressions
- Selection statements
- Loops
- Arrays
- Object instantiation and method calls
- Writing classes
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)
Sample Subgoal Labels

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
Initial Study

- 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

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Results - Quizzes

- Subgoal group performed better (medium effect size) for both average and total
- Subgoal group took more quizzes (number)
- Subgoal group consistently performed better on each quiz

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

- Subgoal group performed better (small effect size) for total
- For average, no statistical difference between groups, but subgoal group has lower variance
- Subgoal group took more exams (number)

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

- 4 quizzes with Explain in Plain English questions
- Analyzed anonymous student responses using SOLO taxonomy

Results

- 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.
## Identifying Risk Factors

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Data Type</th>
<th>r/ρ</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interest in topic</td>
<td>binomial</td>
<td>.24</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Relevant to career</td>
<td>binomial</td>
<td>.27</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Expected grade</td>
<td>continuous</td>
<td>.36</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Expected difficulty</td>
<td>continuous</td>
<td>.30</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>High school GPA</td>
<td>continuous</td>
<td>.26</td>
<td>.001</td>
</tr>
<tr>
<td>College GPA</td>
<td>continuous</td>
<td>.35</td>
<td>&lt;.001</td>
</tr>
</tbody>
</table>

Correlations between Learner Characteristics and Performance for All Students.
## Subgoals Help At Risk Students

### Expected Difficulty

<table>
<thead>
<tr>
<th>Subgoal</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avg Exam (at risk-difficulty)</td>
<td>Avg Exam (all)</td>
</tr>
<tr>
<td>74%</td>
<td>75%</td>
</tr>
</tbody>
</table>

### Below average college GPAs

<table>
<thead>
<tr>
<th>Subgoal</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avg Exam (at risk-college GPA)</td>
<td>Avg Exam (all)</td>
</tr>
<tr>
<td>75%</td>
<td>76%</td>
</tr>
</tbody>
</table>

### Younger students with risk factors

<table>
<thead>
<tr>
<th>Subgoal</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avg Exam (at risk-younger)</td>
<td>Avg Exam (all)</td>
</tr>
<tr>
<td>80%</td>
<td>75%</td>
</tr>
</tbody>
</table>
Persistence

- Students who did not complete all exams OR had average exam score below 70%:
  - Approximately half as many students in the subgoal group vs. control group.

- Based on just exam performance:
  - Students in subgoal group were half as likely to withdraw and half as likely to fail than the control group.

Margulieux, Morrison, & Decker (2020).
International Journal of STEM Education
FUTURE WORK
Rinse / Repeat

- Repeated in Fall 2019
  - Five sections, all instructors
  - Instructor introduced Worked Examples
  - Recorded Worked Examples for YouTube channel
  - Move from paper to eBook implementation for practice problems

- Currently analyzing data
Current

- Website [https://cs1subgoals.org](https://cs1subgoals.org)
- And eBook for general use
    - Worked Examples (text & video)
    - Practice Problems (auto-graded)
    - Assessments
  - Course is “Subgoals”
- Ready for use and adoption for Fall 2020 (great for remote instruction!)
  - Email for your own course
Future

- Phase 2 Grant for:
  - Implementing in Python
  - More professional video recordings
  - Additional topics for Java
    - 2D Array
    - ArrayList
    - Recursion
    - Inheritance / Polymorphism
  - Additional assessments
CONCLUSIONS
Subgoal Labels Beneficial

- In other STEM disciplines
- Improve problem solving performance
- Effects of subgoal learning consistent across new topics
- Subgoal learning can help at risk students
- Subgoal learning can improve persistence
It Works Because

- Having directed scaffolded "recipes" reduces cognitive load
- Practice problems aid in promoting automaticity
Unknown

- Need replication at other institutions, broader population
- Need replication in other programming languages
- Need replication in other CS / STEM classes
Bottom Line

Subgoals had a significant positive effect on overall course performance, even though we found that subgoals did not statistically improve average exam performance.

Subgoals increased persistence, particularly for students at risk.
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Questions?

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