Using Subgoal Labels to Reduce Cognitive Load in Introductory Programming

Briana B. Morrison

bbmorrison@unomaha.edu

BRIDGE LAB

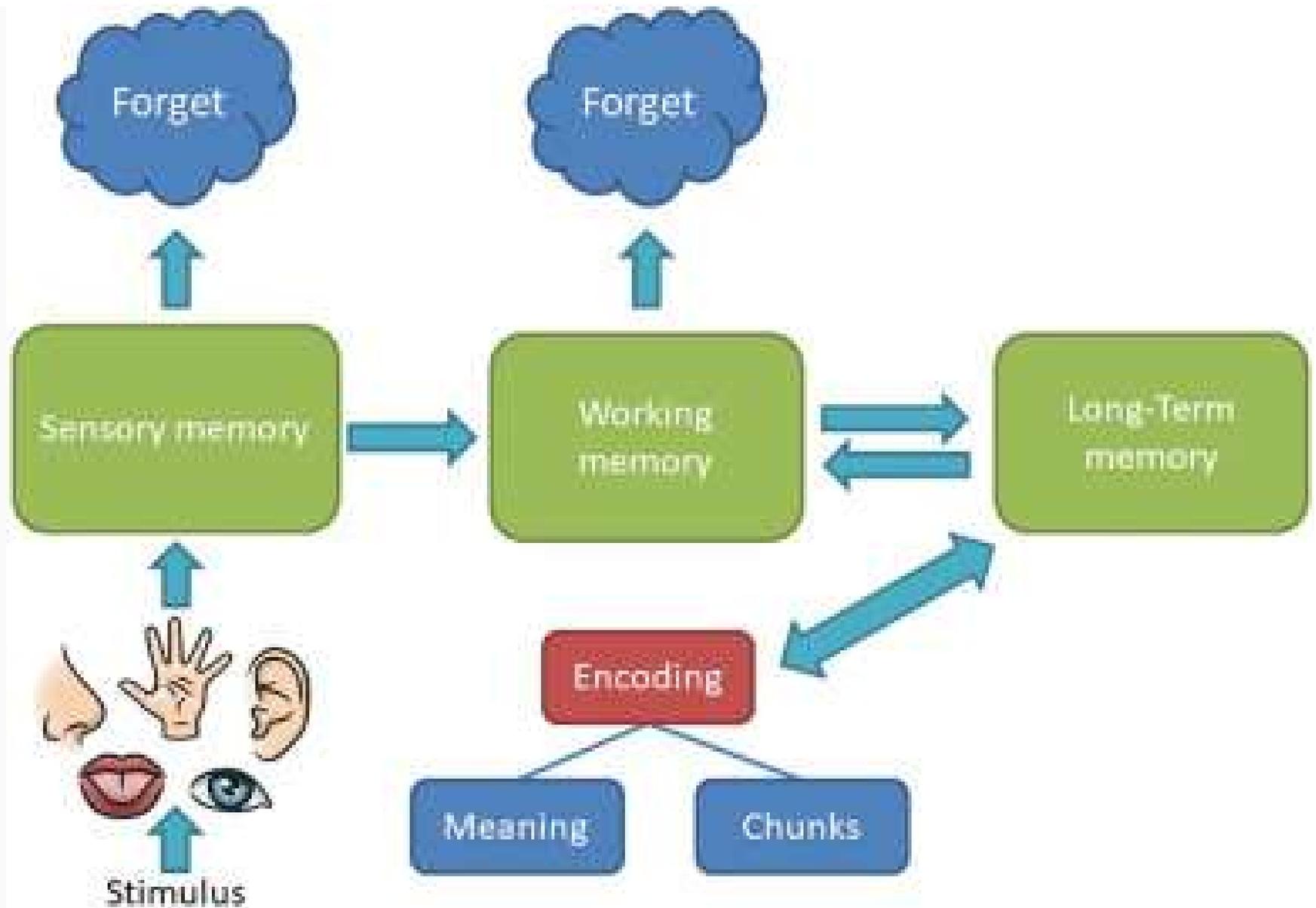UNIVERSITY OF Nebraska Omaha

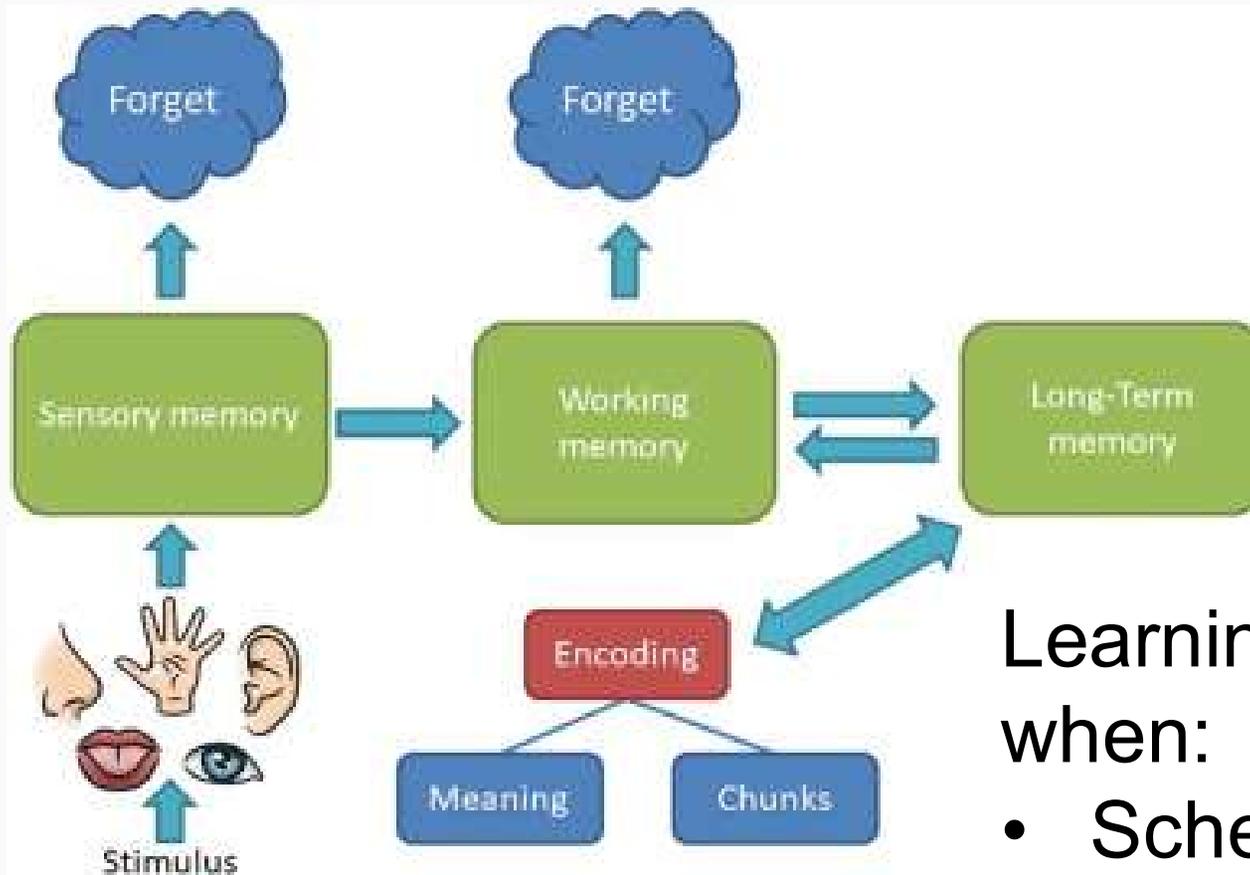# Lauren Margulieux

GeorgiaState University®
COLLEGE OF
EDUCATION
& HUMAN
DEVELOPMENT

Adrienne Decker

University at Buffalo
UB | Department of Engineering Education

bbmorrison@unomaha.edu

UNIVERSITY OF
Nebraska
Omaha

THREATS TO LEARNING

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

bbmorrison@unomaha.edu

Learning occurs when:
- Schema creation
- Assimilation
- Elaboration
- Accommodation

bbmorrison@unomaha.edu

UNIVERSITY OF Nebraska Omaha

Cognitive Load Theory

bbmorrison@unomaha.edu

Programming Example

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

bbmorrison@unomaha.edu

University of Nebraska Omaha

WORKED EXAMPLES

Algebra Worked Example

$$50x \; + \; (-22) \; + \; 42x \; = \; -15$$

$$+22 \qquad\qquad +22$$

$$50x \; + \; 42x \; = \; 7$$

$$(50 + 42)x \qquad = \; 7$$

$$92x \; = \; 7$$

$$\overline{} \qquad \overline{}$$
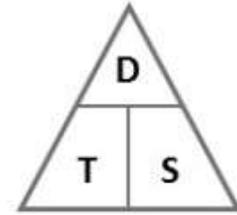
$$92 \qquad\qquad 92$$

$$x \; = \; \frac{7}{92}$$

bbmorrison@unomaha.edu

Worked Example for Speed, Distance, Time problem

Question: A Lamborghini drives for 50 miles at its max speed of 200mph. 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
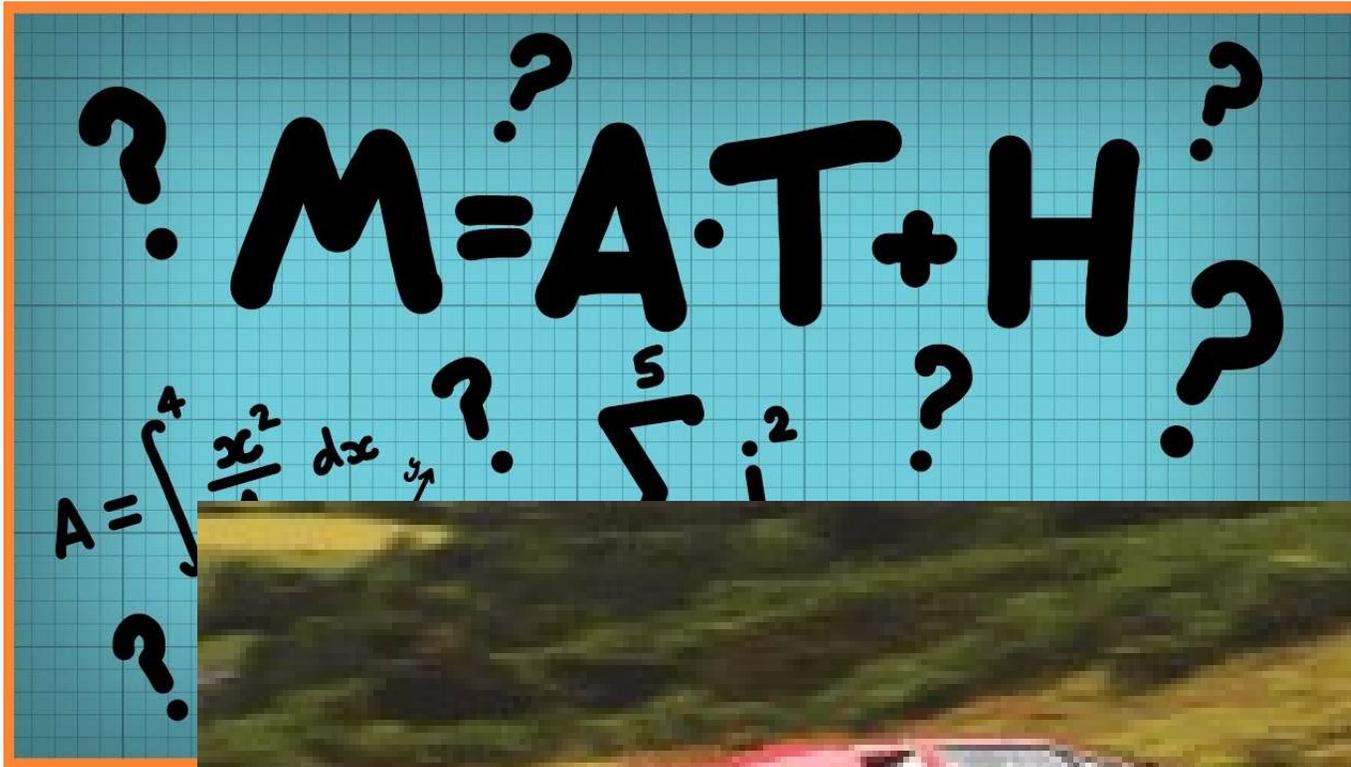Distance: 50 miles
Speed: 200 mph

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

Step 4: 1 hr = 60 minutes
0.25 hrs = 0.25 × 60
0.25 hrs = 15 minutes

Step 5: Time = 15 minutes

bbmorrison@unomaha.edu

Nebraska UNIVERSITY 1 OF
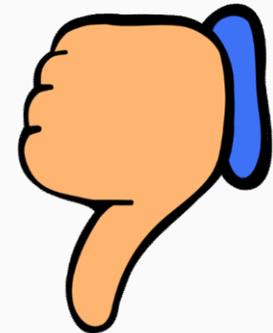Omaha

bbmorrison@unomaha.edu

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

bbmorrison@unomaha.edu

UNIVERSITY OF
Nebraska
Omaha

MINIMIZING THREATS THROUGH INSTRUCTIONAL DESIGN
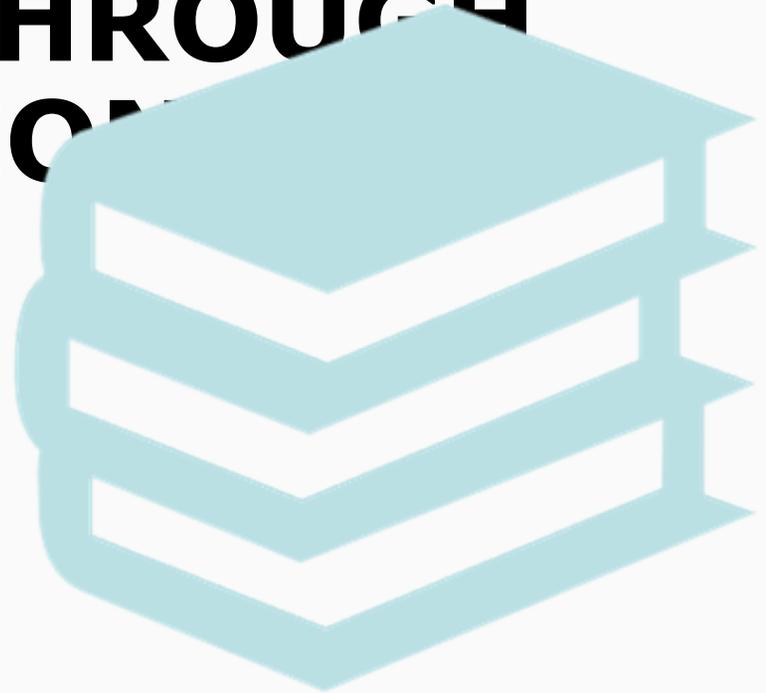
Subgoal Learning

Subgoal Labels

Instructional explanations of the steps

4x - 8 = 2x + 6	
+ 8 = + 8	
- 2x = - 2x	Isolate variable
4x - 2x = 6 + 8	
2x = 14	
/2 = /2	Simplify terms
x = 7	

SG #1

SG #2

Subgoal Learning Framework

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

University of Nebraska Omaha
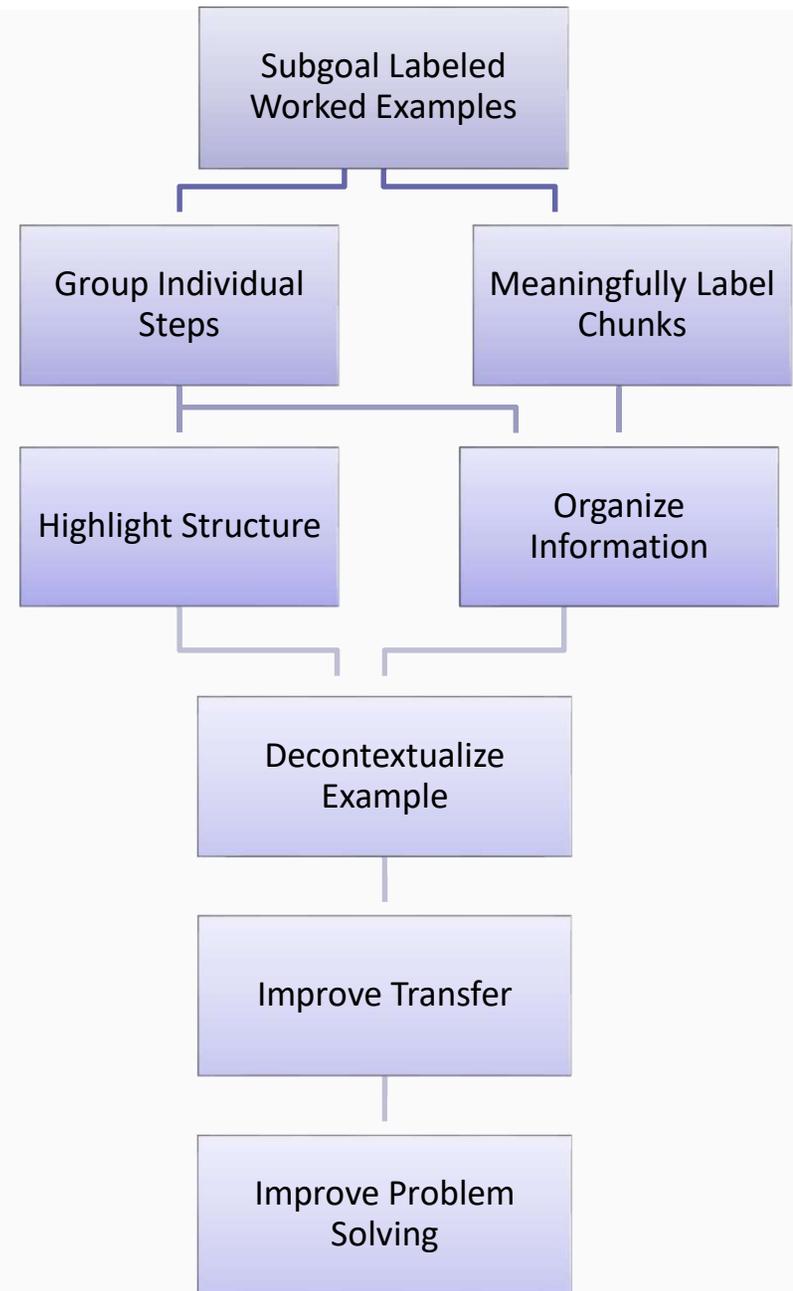
Subgoal Labels

- Shared functional features of working examples helping learner to organize the information (Catrambone, 1998)
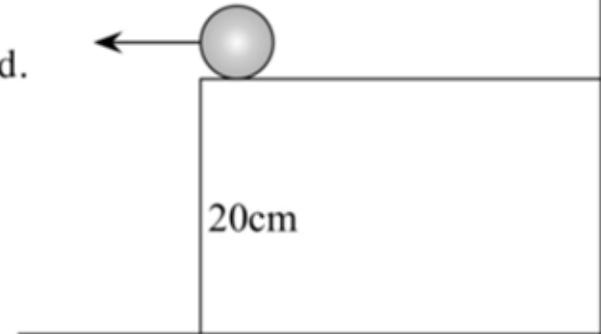
bbmorrison@unomaha.edu

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.

20cm

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

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

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

bbmorrison@unomaha.edu

UNIVERSITY OF
Nebraska
Omaha

Subgoals are NOT Comments

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]   *list containing all the tip values*
sum = 0   *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

bbmorrison@unomaha.edu

- 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

bbmorrison@unomaha.edu

UNIVERSITY 1 OF
Nebraska
Omaha

Topics with Subgoals for CS1

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

bbmorrison@unomaha.edu

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

SME solves problems

KEE solves problems

Complete task analysis

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

bbmorrison@unomaha.edu

UNIVERSITY OF
Nebraska
Omaha
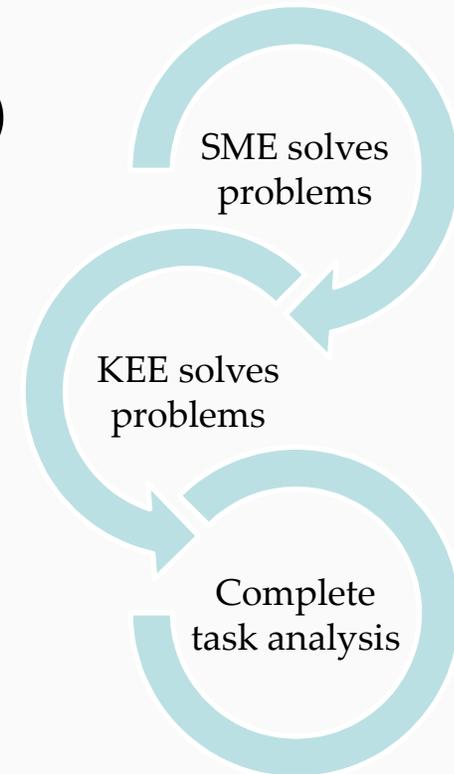
Sample Subgoal Labels

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

UNIVERSITY OF
Nebraska
Omaha

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

bbmorrison@unomaha.edu

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
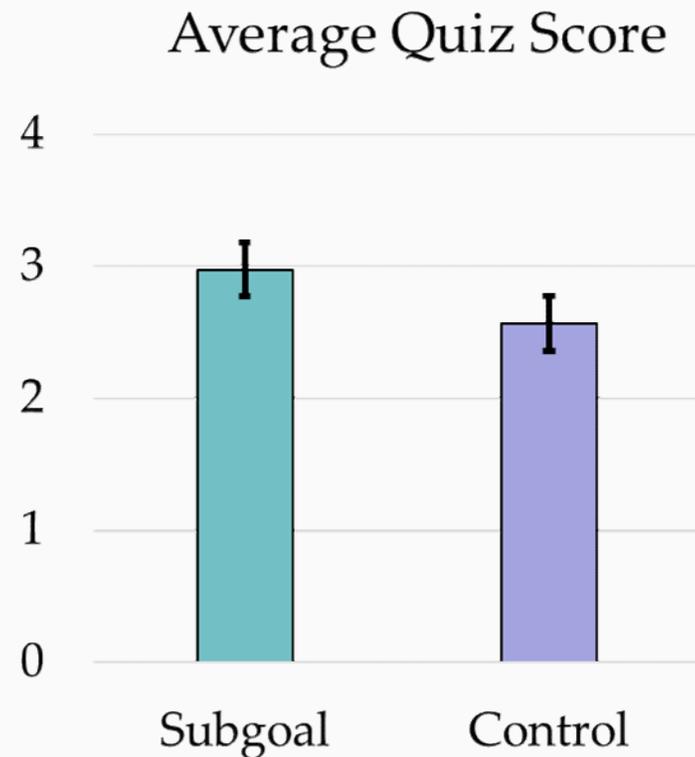
Average Quiz Score

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

bbmorrison@unomaha.edu

UNIVERSITY OF
Nebraska
Omaha

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)

bbmorrison@unomaha.edu

Additional Data Analysis

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

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

bbmorrison@unomaha.edu

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

Characteristic	Data Type	r/ϱ	p
Interest in topic	binomial	.24	<.001
Relevant to career	binomial	.27	<.001
Expected grade	continuous	.36	<.001
Expected difficulty	continuous	.30	<.001
High school GPA	continuous	.26	.001
College GPA	continuous	.35	<.001

Correlations between Learner Characteristics and Performance for All Students.

bbmorrison@unomaha.edu

UNIVERSITY OF Nebraska Omaha

Subgoals Help At Risk Students

- Expected Difficulty

Subgoal		Control	
Avg Exam (at risk-difficulty)	Avg Exam (all)	Avg Exam (at risk-difficulty)	Avg Exam (all)
74%	75%	67%	72%

- Below average college GPAs

Subgoal		Control	
Avg Exam (at risk-college GPA)	Avg Exam (all)	Avg Exam (at risk-college GPA)	Avg Exam (all)
75%	76%	69%	72%

- Younger students with risk factors

Subgoal		Control	
Avg Exam (at risk-younger)	Avg Exam (all)	Avg Exam (at risk-younger)	Avg Exam (all)
80%	75%	72%	72%

Omaha |

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

bbmorrison@unomaha.edu

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
- And eBook for general use
  - http://book.cs1subgoals.org/
    - 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

bbmorrison@unomaha.edu

Future

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

bbmorrison@unomaha.edu

UNIVERSITY OF
Nebraska
Omaha

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

bbmorrison@unomaha.edu

It Works Because

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

bbmorrison@unomaha.edu

Unknown

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

bbmorrison@unomaha.edu

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.

bbmorrison@unomaha.edu

UNIVERSITY OF Nebraska Omaha

Acknowledgements

- This work is funded in part by the National Science Foundation under grants 1712025, 1712231 and 1927906. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the NSF.

bbmorrison@unomaha.edu

Questions?

Briana Morrison

University of Nebraska Omaha

bbmorrison@unomaha.edu

Thank you!

- Collaborators
  - Lauren Margulieux
  - Adrienne Decker
  - Mark Guzidal
  - Richard Catrambone

bbmorrison@unomaha.edu