Building Intelligent Tutoring Systems with the Cognitive Tutor Authoring Tools (CTAT)

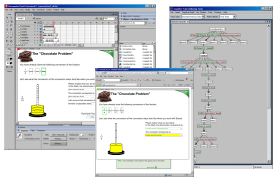
Vincent Aleven and the CTAT team

8th Annual LearnLab Summer School
Pittsburgh, August 6-10, 2012

CTAT Cognitive Tutor Authoring Tools

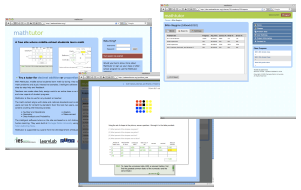
LearnLab
Pittsburgh Science of Learning Center

My Research in Advanced Learning Technologies



CTAT: Authoring tools for rapid development of Intelligent Tutoring Systems with Ken Koedinger

ENGAGE: game for grade 1 science learning
Collaboration between HCII, ETC, and Psych; with Sharon Carver, Justine Cassell, Steven Dow, Matthew Kam, Ken Koedinger, Brad Myers, and Carolyn Rosé



Mathtutor: **free web-based tutors for middle-school math**
with Bruce McLaren
http://mathtutor.web.cmu.edu

Use of graphical representations in tutors for 4th and 5th grade fractions learning
With Nikol Rummel and Martina Rau

Overview

- What is "a tutor?"
  - What are essential characteristics of intelligent tutoring systems?
- Use of CTAT be used to author tutors?
  - Motivation
  - Basic approaches
  - Short movie of authoring with CTAT
  - Examples of projects that have used CTAT
- Evidence of authoring efficiency with CTAT

If you are not in the CTAT track, why might this talk still be of interest?

- Intelligent Tutoring Systems are an effective and increasingly important educational technology
  - Ask President Obama!
- CTAT relevant to most other tracks:
  - *In Vivo:* could do an *in vivo* experiment using CTAT-based tutors as research platform (happens all the time!)
  - EDM/Data Mining: many data sets in the Data Shop were generated using CTAT-built tutors
  - CSCL: Collaborative learning with intelligent tutors is an interesting and important research topic

President Obama on Intelligent Tutoring Systems

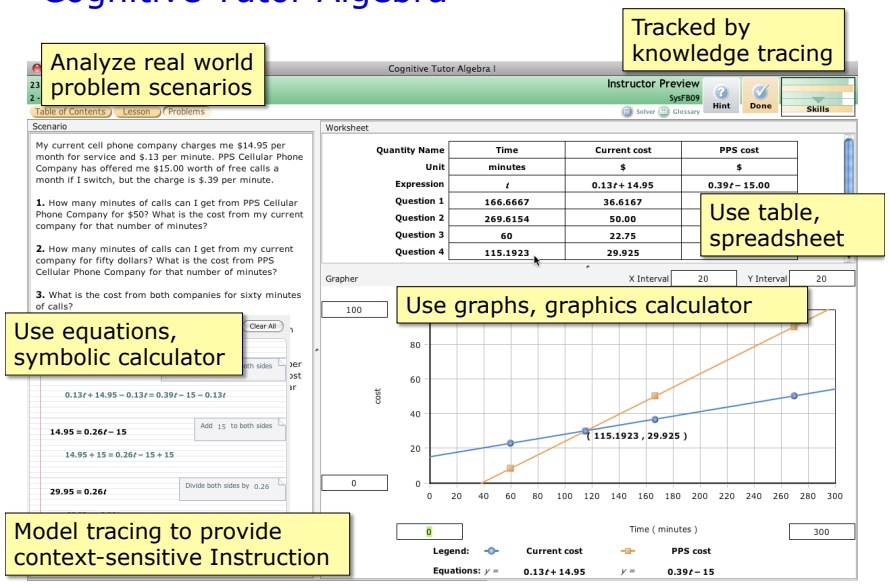
"[W]e will devote more than three percent of our GDP to research and development. …. Just think what this will allow us to accomplish: solar cells as cheap as paint, and green buildings that produce all of the energy they consume; *learning software as effective as a personal tutor;* prosthetics so advanced that you could play the piano again; an expansion of the frontiers of human knowledge about ourselves and world the around us. We can do this."

http://my.barackobama.com/page/community/post/amyhamblin/gGxW3n

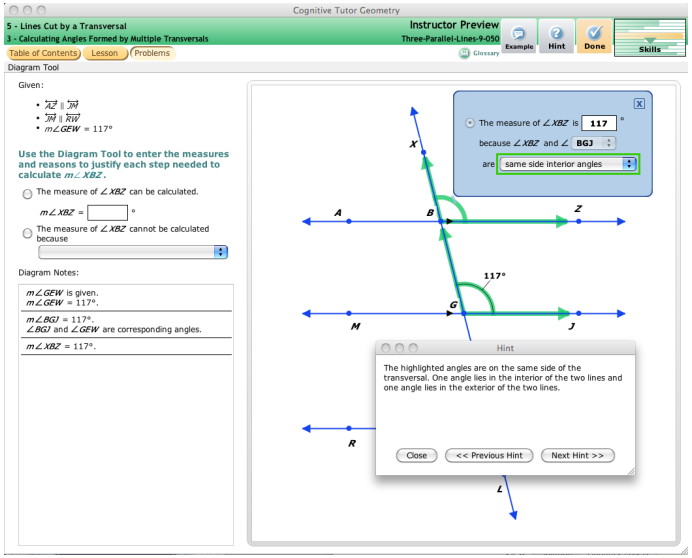
What is an "Intelligent Tutoring System" (ITS)?

- An advanced learning technology
  - Supports "learning by doing" with step-by-step guidance
  - Supports "tutored problem solving"
- Uses artificial intelligence techniques to
  - Provide human tutor-like behavior
  - Be more flexible, diagnostic & adaptive
- Components of an ITS:
  - Interface or problem solving environment, domain knowledge, student model, pedagogical (tutoring) knowledge

Cognitive Tutor Algebra



Cognitive Tutor Geometry



The nested loop of conventional teaching

For each chapter in curriculum

- Read chapter
- For each exercise, solve it
- Teacher gives feedback on all solutions at once
- Take a test on chapter

VanLehn, K. (2006). The behavior of tutoring systems. *International Journal of Artificial Intelligence in Education, 16*(3), 227-265.

The nested loops of Computer-Assisted Instruction (CAI)

For each chapter in curriculum

- Read chapter
- For each exercise
  - Attempt answer
  - Get feedback & hints on answer; try again
  - If mastery is reached, exit loop
- Take a test on chapter

VanLehn, K. (2006). The behavior of tutoring systems. *International Journal of Artificial Intelligence in Education, 16*(3), 227-265.

The nested loops of ITS

For each chapter in curriculum

- Read chapter
- For each exercise
  - For each step in solution
    - Student attempts step
    - Get feedback & hints on step; try again
  - If mastery is reached, exit loop
- Take a test on chapter

VanLehn, K. (2006). The behavior of tutoring systems. *International Journal of Artificial Intelligence in Education, 16*(3), 227-265.

Inner loop options: within-problem guidance offered by ITS

+	Minimal feedback on steps (classifies steps as correct, incorrect, or suboptimal)	
+		Immediate
+		Delayed (two kinds)
+		Demand
+	Error-specific feedback	
+	Hints on the next step	
+	Assessment of knowledge	
–	End-of-problem review of the solution	

VanLehn, K. (2006). The behavior of tutoring systems. *International Journal of Artificial Intelligence in Education, 16*(3), 227-265.

Aleven, V., McLaren, B. M., Sewall, J., & Koedinger, K. R. (2009). A new paradigm for intelligent tutoring systems: Example-tracing tutors. *International Journal of Artificial Intelligence in Education, 19*(2), 105-154.

+	CTAT supports it
–	CTAT does not support it

Outer loop: problem selection options offered by ITS

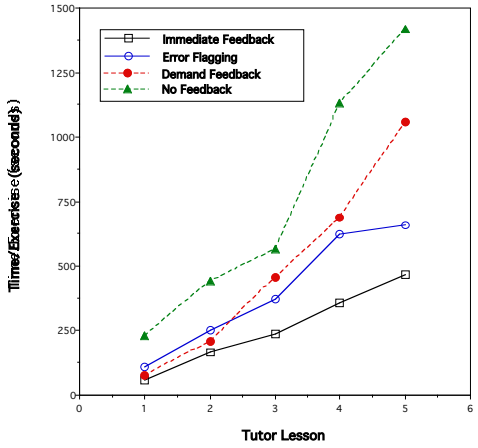
(+)	Student picks
+	Fixed sequence
–	Mastery learning
+	Macro-adaptation (called "Mastery learning" in CTAT and Cognitive Tutor research)

VanLehn, K. (2006). The behavior of tutoring systems. *International Journal of Artificial Intelligence in Education, 16*(3), 227-265.

Aleven, V., McLaren, B. M., Sewall, J., & Koedinger, K. R. (in press). Example-tracing tutors: A new paradigm for intelligent tutoring systems. *International Journal of Artificial Intelligence and Education.*

+	TutorShop supports it
–	TutorShop does not support it
(+)	TutorShop supports a one-off version of it

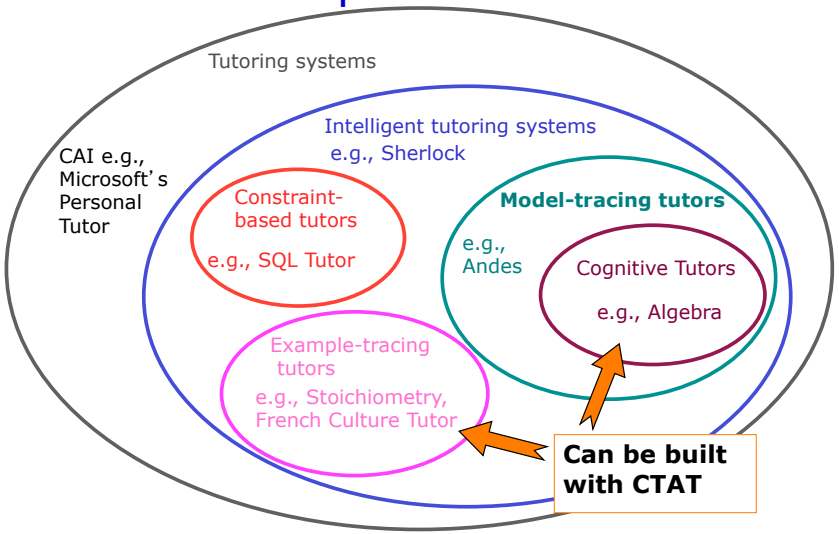
Feedback Studies in LISP Tutor (Corbett & Anderson, 1991)



Time to Complete Programming Problems in LISP Tutor

Immediate Feedback Vs Student-Controlled Feedback

Kinds of Computer Tutors



CTAT motivation: Make tutor development easier and faster!

- Cognitive Tutors:
  - Large student learning gains as a result of detailed cognitive modeling
  - ~200 dev hours per hour of instruction (Koedinger et al., 1997)
  - Requires PhD level cog scientists and AI programmers
- Development costs of instructional technology are, in general, quite high
  - E.g., ~300 dev hours per hour of instruction for Computer Aided Instruction (Murray, 1999)

Murray, T. (1999). Authoring Intelligent Tutoring Systems: An Analysis of the state of the art. *The International Journal of Artificial Intelligence in Education, 10*, 98-129.

Koedinger, K. R., Anderson, J. R., Hadley, W. H., & Mark, M. A. (1997). Intelligent tutoring goes to school in the big city. *The International Journal of Artificial Intelligence in Education, 8,* 30-43.

CTAT goal: broaden the group of targeted authors

- Instructional technology developers
- Instructors (e.g., computer-savvy college professors)
- Researchers interested in intelligent tutoring systems
- Learning sciences researchers using computer-based tutors as platforms for research

How to reduce the authoring cost?

- No programming!
  - Drag & drop interface construction
  - Programming by demonstration
- Human-Computer Interaction methods
  - *Use-driven design:* summer schools, courses, consulting agreements with users, own use
  - User studies, informal & formal comparison studies
- Exploit existing tools
  - Off-the shelf tools: Eclipse, Flash, Excel
- Component-based architecture & standard inter-process communication protocols

Tutors supported by CTAT

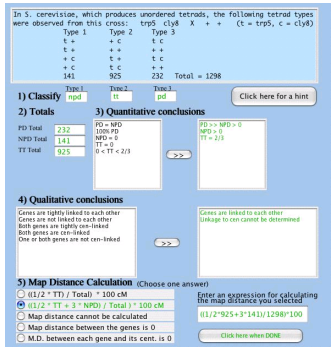
- Cognitive Tutors
  - Difficult to build; for programmers
  - Uses rule-based cognitive model to guide students
  - General for a class of problems
- Example-Tracing Tutors
  - Novel ITS technology
  - Much easier to build; for non-programmers
  - Use generalized examples to guide students
  - Programming by demonstration
  - One problem (or so) at a time

Building an example-tracing tutor

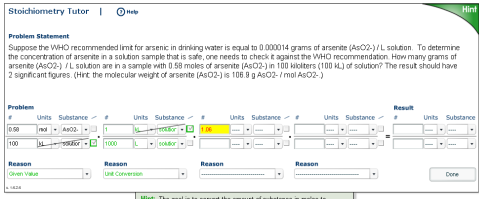
1. Decide on educational objectives
2. Cognitive Task Analysis
3. Design and create a user interface for the tutor
4. Demonstrate correct and incorrect behavior (i.e., create a behavior graph)
   - Alternative strategies, anticipated errors
5. Generalize and annotate the behavior graph
   - Add formulas, ordering constraints
   - Add hints and error messages
   - Label steps with knowledge components
6. Test the tutor
7. (Optional) Use template-based Mass Production to create (near)-isomorphic behavior graphs
8. Deliver on the web - import problem set into LMS (TutorShop)

Movie Showing How an Example-Tracing Tutor is built

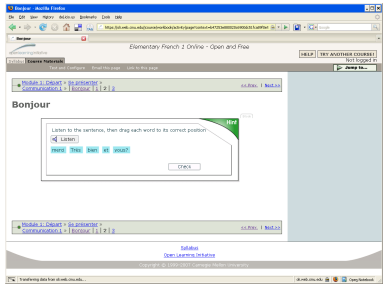
Some CTAT tutors used in online courses and research



Genetics



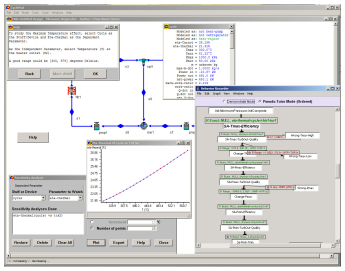
Chemistry

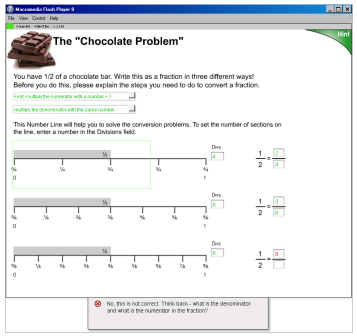


French

Some CTAT tutors used in research

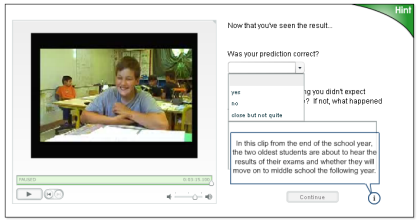
Thermo-dynamics





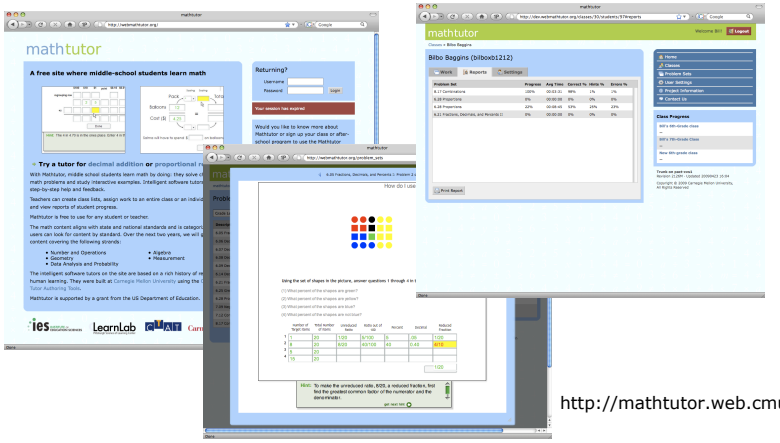
Elementary Math

French (intercultural competence)



Mathtutor: free web-based tutors for middle-school math

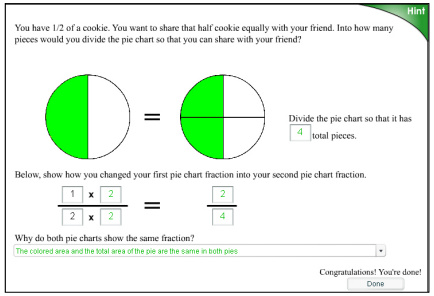
Vincent Aleven, Bruce McLaren

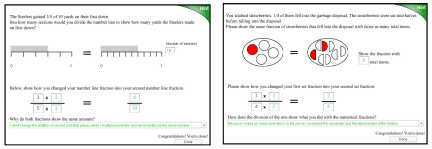


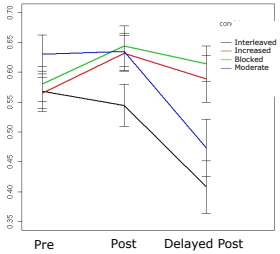
http://mathtutor.web.cmu.edu

In vivo study: Blocked vs interleaved practice with multiple representations

Martina Rau, Nikol Rummel, Vincent Aleven



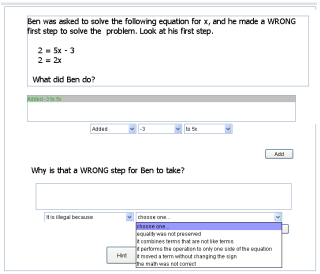




- Interaction effect for test*condition, $F(6, 418) = 5.09$ ($p < .01$)
  - Blocked and increased > interleaved at immediate post-test
  - Blocked and increased > moderate and interleaved at the delayed post-test

In vivo study: Correct and incorrect worked examples in Algebra learning

Julie Booth, Ken Koedinger



Incorrect worked example with self-explanation prompt, built with CTAT

Correct worked example with self-explanation prompt, built with CTAT

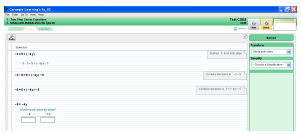
Study Design

Self-Explanation of Correct Examples

Self-Explanation of Incorrect Examples

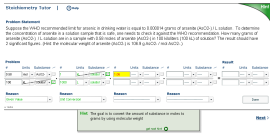
	No	Yes
No	Control	Typical
Yes	Corrective	Typical + Corrective (half of each)

CTAT tutors interleaved with Carnegie Learning Cognitive Tutor



Some tutors for you to look at

- French culture
  - http://www.andrew.cmu.edu/user/aeo/tutor/ibrahim-exp.swf
  - http://www.andrew.cmu.edu/user/aeo/tutor/ibrahim-controlV2.swf



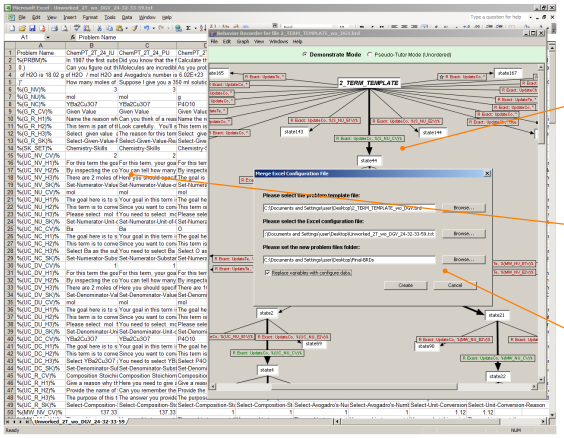
- Stoichiometry
  - http://pslc-qa.andrew.cmu.edu/~pact/tutors/chemstudy/reviewsite/tutors_study3/tutors_study3.htm

Example-tracing algorithm

- Basic idea: To complete a problem, student must complete one path through the graph
- Example tracer *flexibly* compares student solution steps against a graph
  - Keeps track of which paths are consistent with student steps so far
  - Can maintain *multiple parallel interpretations* of student behavior
  - Accepts student actions as correct when they are consistent with prior actions – i.e., occur on a solution path that all accepted prior actions are on

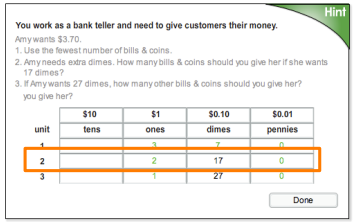
Aleven, V., McLaren, B. M., Sewall, J., & Koedinger, K. R. (2009). A new paradigm for intelligent tutoring systems: Example-tracing tutors. *International Journal of Artificial Intelligence in Education*, *19*(2), 105-154.

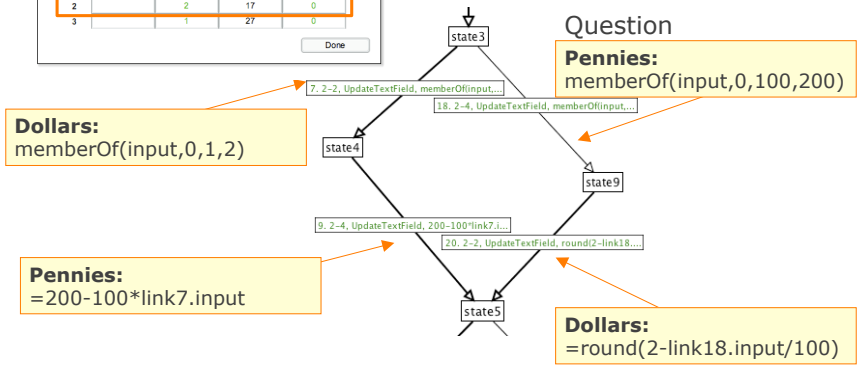
Mass Production: template-based tutor authoring to generate (near-) isomorphic behavior graphs



1. Turn Behavior Graph into template (insert variables)
2. Fill in spreadsheet with problem-specific info; provide variable values per problem
3. Merge spreadsheet values into template

Example: Use of formulas





Vote-with-your-feet evidence of CTAT's utility

- Over 500 CTAT users in summer schools, courses, workshops, research, and tutor development projects
  - Domains: mathematics, chemistry, genetics, French culture, Chinese, ESL, thermodynamics
  - At least 44 research studies built tutors and deployed in real educational settings
- In the past two years
  - CTAT was downloaded 6,600 times
  - the CTAT website drew over 2.9M hits from 164k unique visitors
  - URL: http://ctat.pact.cs.cmu.edu

Cost estimates from large-scale development efforts

- Historic estimate: it takes 200-300 hours to create 1 hour of ITS instruction, by skilled AI programmers (Anderson, 1991; Koedinger et al., 1997; Murray, 2003; Woolf & Cunningham, 1987)
- Project-level comparisons:
  - + Realism, all phases of tutor development
  - – High variability in terms of developer experience, outcomes (type and complexity of tutors), within-project economy-of-scale
  - – Many arbitrary choices in deriving estimates
  - – Can be difficult to track
  - – Can be difficult to separate tool development and tutor development

Development time estimates

Project Title	Domain	Studies	Students	Instructional Time	Development Time	Time Ratio
Improving Skill at Solving Equations through Better Encoding of Algebraic Concepts	Middle and High School Math - Algebra	3	268	16 mins each for 2 conditions	~120 hrs	240:1
Using Elaborated Explanations to Support Geometry Learning	Geometry	1	90	30 mins	~2 months	720:1
The Self-Assessment Tutor	Geometry - Angles, Quadrilaterals	1	67	45 mins	~9 weeks	540:1
Enhancing Learning Through Worked Examples with Interactive Graphics	Algebra - Equation Models of Problem Situations	1	60-120	~3 hrs	~260 hrs	87:1
Fluency and Sense Making in Elementary Math Learning	4th-Grade Math - Whole-number division	1	~35	2.5 hrs each for 2 conditions plus 1 hr of assessment	~4 months	107:1
The Fractions Tutor	6th-Grade Math - Fraction Conversion, Fraction Addition	1	132	2.5 hours each for 4 conditions	12 weeks	48:1
Effect of Personalization and Worked Examples in the Solving of Stoichiometry	Chemistry Stoichiometry	4	223	12 hrs	1016 hrs	85:1

Discussion of cost-effectiveness

- All tutors were used in actual classrooms
- Small projects worse than historical estimates (1:200 to 1:300)
- Large projects (> 3 hrs.) 3-4 times better (1:50 to 1:100)
- Factor in that programmers cost 1.5-2 times as much as non-programmer developers: total savings 4-8 times

- Caveats: Rough estimates, historic estimates based on larger projects

That's all for now!