CogSketch and Education
How CogSketch Might Be Used in Education

- Eventually, like a calculator
  - Always available
  - Useful across a broad variety of tasks
- But with more scaffolding
  - Access to intelligent tutors and coaches built in
    - Exploit science base developed by SILC

Our Vision:
Sketch understanding software to help students learn could be made widely available within 5 years
Current CogSketch Education Projects

- Problem: Helping students understand spatial layouts and use terminology correctly
- Idea: Provide scaffolds in sketching exercises to coach students
- Software: Worksheets
- Maria Chang

- Problem: Students have trouble using sketches to communicate their ideas
- Idea: Make an explanation coach for students to practice with.
- Software: the Design Coach
- Jon Wetzel
Worksheets

• Simple pedagogical model
  – Student is given a sketching task
  – Doing the sketch should help learning by
    • Forcing the student to think about the topic
    • Retrieve potentially relevant knowledge
    • Filter by what makes sense to depict
    • Depict relevant knowledge in a way that communicates to someone

• CogSketch potentially provides value by
  – Giving advice, via analogy with teacher-drawn sketch
  – Proving teacher/experimenter with digital artifact that can be more deeply analyzed
    • Full timing data available
Worksheet Example

Draw a diagram that shows the greenhouse effect.

- First, draw 3 entities:
  - the Sun
  - the Earth
  - the Earth’s atmosphere

- Next, draw the radiation emitted and absorbed across the 3 entities. There are two kinds of radiation: short wave radiation includes ultra-violet and visible light and long wave radiation includes infrared. Draw 3 relation arrows to show:
  - radiation going from the Sun to the Earth
  - radiation going from the Earth to the Earth’s atmosphere
  - radiation going from the Earth’s atmosphere to the Earth
Worksheet Example: Draw and Label

Student draws glyphs...

...and labels them, using options provided by worksheet author.
Worksheet Example: Relations

Student draws and labels relations

The student hits feedback and...
Worksheet Example: Suggestions

Tutor makes suggestions by comparing solution sketch and student’s sketch.

When a student selects a suggestion, the glyphs are highlighted in green.
Worksheet Example: Success!

Your sketch looks good to me!

Suggestions for Sketch sc-demo-greenhouse

See more suggestions...
Update suggestions

Earth's Atmosphere

Short wave
Long wave
Long wave radiation

Absorbed across the 3 entities. There are two kinds of waves. Ultra-violet and visible light and long wave radiation shows to show.
Authoring Environment for Worksheets

• Can create new worksheets without programming
  – Sketch answer
  – Select included concepts
  – Mark important facts & provide advice

• Limitation
  – Authoring currently requires familiarity with the CogSketch knowledge base (outlined later)
Making a New Worksheet: Startup

- Click “Create New Worksheets” on the start screen (or choose “New Worksheet” from menu)
- A new sketch plus the Worksheet Properties dialog appears
  - **Edit menu / Worksheet Property Editor** can also be used to open the property dialog.
Making a New Worksheet: Problem Statement and UI Skin

The problem statement gives instructions to the students.

The skin determines which user-interface controls are available.

User-interaction locks can be used to prevent the user from performing actions on glyphs provided on the workspace subsketch.
Example Skins

Experiment Workspace, minimal

Worksheet Workspace (default skin)
Making a New Worksheet: Selecting relevant knowledge

In this tab, you select relevant collections for labeling glyphs, as well as relations and annotations.

Search for new collections by name here.

You can change the short description a student will see.

Scroll down for relations and annotations.
Making a New Worksheet: Adding a solution

- If you are including a solution, say so on the Solutions tab by clicking the check box.
- Draw your solution on the Solution subsketch, and label it using the collections, relations, and annotations you set up in the previous tab.
- You may also remove the feedback button if desired (e.g. for an experiment or an exam).
Making a New Worksheet: Two Types of Advice

Select Important Facts
Could be any fact in sketch, for example:
- Relation arrows (e.g. greenhouse example)
- Spatial information (e.g. containment)
- Numerical values on annotations
- What concept a glyph represents (i.e. its label)

Quantitative ink comparison
Ink in student sketch vs ink in solution sketch

You can use a fixed image layer to add background images.
Making a New Worksheet: Providing Advice for Facts

- Select important facts
- Provide advice to be presented if analogous facts are not true in student sketch
Making a New Worksheet:
Providing Advice for Numerical Annotations

You can specify a range of acceptable values and advice for each quantity.

This fact will be associated with the glyph that was annotated (not the annotation itself).

If your important fact involves a numerical value, the fact you are looking for is: `visualQuantityQuantitativeMeasurement`
Making a New Worksheet: Providing Advice for Q. Ink Comparisons

- Select glyphs that need to be in the right place
- Specify tolerance and advice
- Advice given if glyph looks different enough

Tolerance is displayed for selected glyph on the solution subsketch.
Making a New Worksheet: Testing

• Save first!
• Switch to workspace and sketch a perfect solution
  – Verify that solution works
• Then try:
  – Deleting glyphs
  – Moving glyphs
  – Resizing/rotating glyphs
  – Making the most bizarre variations you can think of
• Do pilot testing on friends and small groups of students
Making a New Worksheet: Grading

Multiple grading criteria available (scroll down for more)

You assign point values to each item

List of items to grade is populated automatically

Points are normalized automatically
Making a New Worksheet: Security

• Add a password to prevent students/subjects from viewing the solution subsketch and editing the worksheet properties
CogSketch gradebook

- A tool for organizing and grading sketches submitted by students.

- The gradebook can contain multiple classes, each of which can have multiple assignments.
Gradebook: Adding Classes

• The very first time you open the gradebook, no classes will be defined.

• Click the **New class** button:

![New class dialog box](image)

• The titles can be anything meaningful to you. Here, I’ve used the secondary title to say that the course happened in the Spring quarter.
Gradebook: Adding assignments and students

• Double-clicking a class shows the assignments and students for that class:

The **New assignment** and **New student** buttons are used to define assignments and students.
Gradebook: Adding sketches

• Double-clicking an assignment shows the sketches submitted for that assignment:

• Double-clicking a student shows the sketches submitted by that student.
Gradebook: Adding sketches

• There are a couple ways to add sketches:
  – Drag-and-drop
  – **Add sketches** button

• Either way, you’ll be prompted for further information:
Gradebook: grading

• Worksheets can be graded using our automated grading system.

• One sketch in an assignment must be defined as the solution sketch:

• Grading criteria are used from solution sketch and applied to the students’ submitted sketches.

• Click the Grade worksheets button and grade reports will be generated for all the selected sketches or all the sketches shown on the screen if none are selected.
Gradebook: example grade report

Grading Report

student: usher
worksheet: layers-1
(D:/temp/grading-test/grades_input/layers-1.sl)

Scoring Details

Missing Glyphs
For each of the glyphs listed below, points are awarded if the student has included the glyph in their sketch.

Student Score: 25 / 25 points
- [5 points] Crust
- [5 points] Inner core
- [5 points] Mantle
- [5 points] Object-7383
- [5 points] Outer core

Non-Quantitative Facts Important for Tutoring
The following are the facts marked as important for tutoring that don't mention quantitative values. Points are awarded if the tutor doesn't find anything wrong with the corresponding facts in the student's sketch.

Student Score: 10 / 30 points
- [10 points] (objectContains "Outer core" "Inner core")
- [0 points] (objectContains "Mantle" "Outer core")

Correct Answer would be:
(objectContains "Mantle" "Outer core")

Student had the following similar facts:
(objectContains "Crust" "Outer core")
(objectContains "Inner core" (GlyphFn Object-7369 User-Drawn-Sketch-Layer-688))

Total Score
normalized: 63.0 / 100 points
raw: 51 / 81 points
Worksheet Classroom Pilot Studies

• Goal: Formative evaluation
  – Gather data needed to improve representations and algorithms
  – Work out how to make sketch worksheets practical in classrooms and for homework assignments

• First pilot Fall 2009, Brad Sageman’s Geo 201: Surface Processes
  – Round 1: 10 students (out of 28), extra credit
    • 3 fault identification, 1 reconstruction of process sequence
  – Round 2: Required; carbon cycle: Identify sources, sinks, and flows
Worksheet Classroom Pilots (cont.)

- **Earth 201 at NU**
  - Earth Systems Revealed (Intro Geology)
  - Prof. Andrew Jacobson
- **4 required worksheet assignments**
  - 3 fault identification
  - 1 relative age dating
- **2 extra credit worksheets**
  - Carbon cycle
  - Greenhouse effect

- **Geology 110 at Carleton College**
  - Introductory Geoscience
  - Prof. Sarah Titus
- **4 required worksheet assignments**
  - Mid-ocean ridge spreading, illustrating plate tectonics, developed by Basil Tikoff & Maria Chang
Sketching as an Assessment Tool

• Can sketching be used to measure student understanding?
  – Evidence so far suggests yes, as discussed next
  – But more research is needed

• Implications
  – Potentially can be used to assess student understanding
  – Sketch-based intelligent tutors can use assessments to better guide students
Indirect measures of expertise

- Number of long pauses while copying equations inversely related to expertise
  - Cheng & Rojas-Anaya, 2007

- Distance between elements while copying equations reflects understanding of operator precedence in equations
  - Landy & Goldstone, 2007

- **Conjecture:** Properties of sketching can provide indirect measurement of expertise
  - CogSketch captures conceptually segmented ink, with timing information
  - Could gather data in experiments far easier than video
  - Could build assessment tools into classroom software
Pilot study: Louis Gomez

• Task: College students copied figures from a standard high school textbook
  – 10 novices (no college science courses)
  – 10 experts (at least two college biology courses, mostly pre-med)

• Results: Experts started at the beginning of the process, novices stated with visually salient parts
GeoSketch study
(Jee et al, CogSci 09)

- Can CogSketch can be used to detect differences in geoscience knowledge?

Participants:
- 10 Novices—intro psychology students
- 10 Geoscience students—Geoscience undergrads and grad students

Method:
- Participants sketched 9 geoscience images and 3 non-geoscience images
- 4 causal diagrams, 8 photographs
- Three different task conditions (4 sketches per condition; 3 minutes allotted per sketch):
  1. Tracing over image
  2. Copying while image present
  3. Reproducing from memory. Study for 30s, then reproducing the image from memory
Geo students include more relations


Causal/cycle diagram  Geo student sketch  Novice sketch

No differences for Control sketch
Geo students include more key structures

Geo formation (key structures shown)    Geo student sketch    Novice sketch

No differences for Control sketches
Summary of results

For causal diagrams:
• Geoscience students include more causal knowledge, relative to novices
  – They focus more on depicting relational information and less on depicting the objects present
  – They begin their sketches with causal/relational information more often than novices

For photos of geological formations:
• Geoscience students include more geologically relevant structures
  – Relevant structures often idealized
Design Coach: Setting and Problem

Engineering Design and Communication Course (EDC) at Northwestern University

Problem:
Students have trouble using sketches to communicate
Explaining Designs with Sketches

This is a flux capacitor. It allows us to travel through time...

Early design explanations:
• Sketches are roughly drawn and ambiguous
• Language clarifies drawing and adds teleological information
Like human-to-human sketching:
• Student supplements sketch with language
• Qualitative reasoning allows coach to understand mechanisms
• Coach provides feedback when explanation is unclear
Students Create Multiple Sketches

- Multiple sketches depict the design in different operating states
- User draws arrows between these states, forming a comic graph
Students Create Multiple Sketches

- Multiple sketches depict the design in different operating states
- User draws arrows between these states, forming a comic graph
Students Add Sentences

• Template-based entry of sentences
• Subject-Verb-Object form, may be compound

Generates facts which use the same knowledge representations as in the sketch.
Generating Feedback for Students

Design Coach checks for:

1. Unexplained or impossible motions depicted in the sketch [Wetzel & Forbus, 2008]

2. Unsupported or contradictory template-based sentences [Wetzel & Forbus, 2009]

3. User input errors
Design Coach Classroom Progress

• 2009-2010
  – Tested coverage on past design projects
  – Understood 16 out of 39 projects (20 were in our domain, mechanics)
  – See Wetzel & Forbus, IAAI09

• 2010-2011
  – Pull out studies using optional homework assignment
  – Small sample size
Design Coach Classroom Progress

• 2011-2012
  – Used as a mandatory homework assignment in one section in Fall, two in Winter (EDC has 16 students per section)
  – Collected 88 explanations altogether
    • Using these to further improve the coach
  – Added teleological language
    • Functions and ways of achieving them
    • Students explain and get feedback on the purposes of their design
  – Surveys on sketching anxiety were offered before and after activity
Sketching Anxiety Survey

- Based on math anxiety survey by Beilock et al (2010)
- Students begin more nervous about sketching in engineering context:
  - Analysis of pre- and post- indicated possible effect of CogSketch Design Coach assignment on anxiety and skill
    - Further research required to confirm and explain

![Sketching for fun at a party with friends](image1)

![Sketching an engineering design](image2)
Current Design Coach Capabilities

• Focused on mechanical designs
  – Supports forces, motion, springs, and gears
• Teleological vocabulary includes:
  – Increasing comfort
  – Containing/holding
  – Adapting to variable size
  – Attaching/detaching
• Teleology will be extended over time to cover engineering project domains
Summary

• Worksheets are designed to help students learn spatial phenomena, especially layouts
  – Could be used as homework assignments or off-line tutorials
  – Even simple tasks, like copying a diagram, may provide useful assessment data

• CogSketch can potentially be combined with other AI techniques to do sophisticated tutoring in spatial domains
  – Design Coach is a test of this hypothesis, underway