C-TOOLS: Concept-Connector Tools for Online Learning in Science
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Background

During the last four years, the *C-TOOLS* project has successfully developed an online concept mapping tool that allows students to use a "Concept-Connector" drawing template to build concept maps (Novak & Gowin, 1984) and receive immediate visual feedback regarding the correctness of their choices from the software agent "Robograder" (Figure 1, http://ctools.msu.edu/).

By design, this software was used by an initial core faculty in four science disciplines, chemistry, biology, geology, physics to develop and test online homework exercises for science and non-science majors in large enrollment introductory STEM courses. As the number of faculty using the software grew, a number of education research projects were initiated. The results of this research have appeared in three peer-reviewed manuscripts (Luckie et al 2003, Luckie et al 2004, Harrison et al 2004) and cited in three Pathways to Scientific Teaching articles in the journal *Frontiers in Ecology and the Environment* (Ebert-May et al 2005, Hodder et al 2005, Williams et al 2004). In addition, one of our faculty members has published a new finding (Sibley et al 2007). Duncan Sibley adapted his use of concept maps to represent geological cycles in a visual model familiar to physical science faculty known as "box diagrams" (Safayen et al 2005). He has preliminary data that indicates these may increase student learning *and* we believe this approach is well-suited for automated grading by C-TOOLS online software.

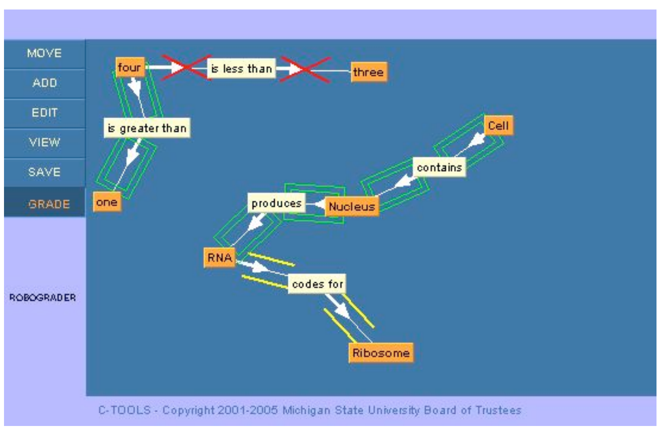

Figure 1: The Concept-Connector drawing tool with Robograder engaged. Red X's, and green or yellow halos indicate "incorrect," "correct" and "unknown" respectively as automatic feedback to students.

Box model diagram pilot study

"Project 2061 Benchmarks" (AAAS 1993) identifies understanding systems as a common cross-disciplinary theme. Although this report focused on the K-12 education, assessment data indicate that undergraduates need significantly more practice to understand systems. Tracing matter through various reservoirs is a fundamental aspect of Earth System Science that has its roots in Hutton (1788) and continues as an important area of research in modern geology (Cook et al. 1998, Kerrick and Caldiera, 1998, Meissner and Mooney 1998; Wallman 2001, Newell et al., 2005, Plank and Langmuir 1998, Simon and Lécuyer 2005). Thus, while systems analysis is an important skill, there are few examples of how to design effective practice and assessment instruments that foster this skill, particularly in large courses. Results from preliminary observations and a descriptive study suggest that box diagrams are effective instruments for instruction and assessment of students understanding of Earth systems (Sibley et al 2007). Students' box diagrams completed in several sections of a non-majors *Global Change* course (without the aid of C-TOOLS software) were analyzed by categorizing common mistakes, confirming the prevalence of those mistakes with objective questions on exams and interviewing students (Sibley et al 2007).

- The most persistent problem for students is **chemical change**. This is a common source of error in their representations of the water, rock and carbon cycle. For example, in a carbon cycle box diagram exam question over 80% of the students converted $C_6H_{12}O_6$ to $CaCO_3$ via the process of burial. Interestingly, these same students used photosynthesis and respiration appropriately in a different part of the same diagram, suggesting that they know the words but do not appreciate that chemical change involves conservation of matter.

- A second common problem is that students **fail to recognize processes and reservoirs that are invisible**. This is related to students' difficulty with chemical change but it goes beyond that to include misconceptions such as underground lakes and streams, a molten mantle, and mountains pushed up by colliding plates.

- A third, general problem is that students are **more aware of reservoirs** than the processes that move and/or change material. For example, students use the terms weathering, erosion and deposition between rocks at the surface and sediments but often confuse weathering and erosion.

A box model diagram is similar to a concept map in which nodes are reservoirs or/and or forms of matter and links are processes that move and/or change matter (Figure 2).

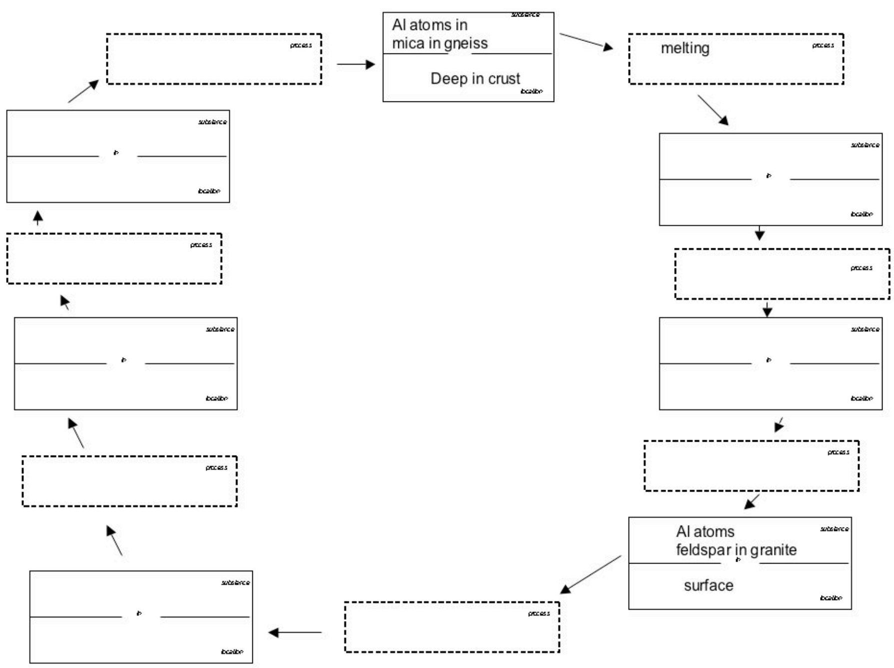

Figure 2. A closed loop rock cycle question that requires students to trace aluminum atoms. The most common error in this exercise is omitting minerals such that a reservoir might be labeled as Al in sandstone as opposed to Al in mica in sandstone.

One can construct a large number of practice exercises simply by changing the starting materials, number of boxes to be used and/or by filling in some boxes to constrain possible answers. The advantage of C-TOOLS with Robograder is that students in large courses may practice and complete many diagrams similar to that shown in Figure 2 and receive instantaneous online feedback that serves as a prompt to help students reflect on their learning *while* building their cycle. In addition to completing assignments, students can build their own box diagrams and check the results. We predicted that students would learn the more concrete reservoirs before the more abstract processes. However, we also predict that practice with C-TOOLS and Robograder will help students reinforce their understanding of more abstract processed that link reservoirs.

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