A problem-sorting task detects changes in undergraduate biological expertise over a single semester

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Rationale: Recent calls for undergraduate biology reform, from AAAS’ *Vision and Change* to the University’s Undergraduate Learning Goals, share similar aspirations: to produce a generation of individuals who can organize, use, make connections among, and communicate about scientific knowledge. Achieving this goal requires students to gain disciplinary expertise. Previous work has shown that experts organize, access, and apply disciplinary knowledge differently than novices, and that changes in expertise are measurable. Drawing on a rich history of card-sorting from the cognitive sciences, we investigated whether and how introductory biology students changed the ways they organized and linked biological ideas over a single semester of introductory biology.

Objective: Our research had two objectives. First, we aimed to determine whether the Biology Card Sorting Task (BCST; J. I. Smith and colleagues 2013) – first developed to discern differences between introductory nonmajors and biology faculty – was robust enough to detect changes in student expertise over a single semester of introductory biology. Assuming that the BCST could detect such changes, we next aimed to explore which factors best predicted population-level changes in student biological expertise.

Methods: Over three semesters, we administered the Biology Card Sorting Task (BCST) to 751 students enrolled in fifteen sections of introductory biology. The BCST has people sort, but not solve, common biology problems according to what they know about biology. Each course section’s students sorted the same 16 biology problems under one of two different sorting conditions: one in which students were given *Vision and Change* deep-conceptual categories, and one in which students were asked to construct their own categories. Courses included first and second semesters of introductory biology, and sorted broadly into either cell-molecular or organismal-population topics. Students undertook the BCST at the beginning (first or second week) and again at the end (penultimate or final week) of a semester of introductory biology. We used three metrics: pair and triplet associations, and edit distance – a measure of problem moves required to achieve a deep-conceptual sort. We analyzed results from these metrics using correlative statistics to address our first objective, and linear mixed modeling to address our second objective. (This investigation was reviewed, the protocol approved, and the study determined exempt by the university’s Institutional Review Board, IRB# x14-026e, File ID: i045259.)

Results: The BCST did detect changes in student expertise over a single semester, satisfying our first objective. Students used a combination of superficial, deep, and yet-uncharacterized ways of organizing and connecting their biological knowledge, but made significantly more deep-conceptual problem associations by the end of a semester of biology. To address our second objective, we found that students in second-semester biology courses made significantly greater gains than students in first-semester courses, regardless of course topic. Students also showed significantly greater gains in expertise when provided with the deep-conceptual framework than when asked to organize the problems themselves – again regardless of course topic.

Implications for Teaching and Learning: Consistent with expertise research findings, our data show that gains in expertise occur when students connect ideas together on a conceptual framework that they must have access to, before they can generate it themselves. This points to the importance of planning and organizing curricula and course activities around the deep concepts of biology, providing access to the deep conceptual framework, and returning frequently to that framework – especially with populations of novices in introductory courses. Instructors can help students advance toward biological expertise by focusing on deep concepts – not merely topics – and by demonstrating how important facts and ideas relate to other biological topics and ideas.