

## ARTICLE

# Assessing Development of an Interdisciplinary Perspective in an Undergraduate Neuroscience Course

Kevin M. Crisp<sup>1</sup> & Gary M. Muir<sup>2</sup>

<sup>1</sup>Biology Department & Neuroscience Program; <sup>2</sup>Psychology Department & Neuroscience Program, St. Olaf College, Northfield, MN 55057.

Neuroscience is an intrinsically interdisciplinary (ID) field yet little has been published regarding assessment of ID learning in undergraduate neuroscience students. This study attempted to empirically assess the development of an interdisciplinary perspective in 25 undergraduate neuroscience students in a neuroscience program core course. Data were collected using two simple assessment instruments: 1) written responses to the open-ended question “*What is neuroscience?*” and 2) a *term-discipline relevance survey* in which students indicated all

disciplinary perspectives to which terms (such as electrode, taste, dx/dt) were relevant. Comparison of student responses early in the course (week 1 or 5) and at the end of the course (week 15) showed evidence of development of an interdisciplinary perspective, with students using significantly more integrative terms in their responses and demonstrating an increased awareness of the complexity of the field of neuroscience.

*Key words: assessment, integration, interdisciplinary learning, content analysis, intended learning outcomes*

Neuroscience is an inherently interdisciplinary (ID) field of study. Although Neuroscience may itself be considered a discipline (Snyder, 1985), there remains little question that the breadth and depth of knowledge falling within the neuroscience domain intersects a large number of traditional disciplines such as Biology, Psychology, Chemistry, and Physics. As instructors, the interdisciplinary nature of neuroscience should also be viewed as an excellent opportunity to educate our students not just about neuroscience content, but also in important ways about complex, real-world problems - such as understanding the mind - that will require interdisciplinary solutions. As Newell (2010) states, “Individual disciplines, indeed individual perspectives whatever their source, can illuminate some single aspect of those complex problems, and multiple perspectives can offer alternative partial solutions, but only interdisciplinarity holds out the hope of moving towards full or comprehensive solutions.” (p.364). This thinking at least partially underlies initiatives to facilitate ID learning and research at the national level implemented by Project Kaleidoscope (PKAL), the American Association of Colleges and Universities (AAC&U) and the National Academy of Sciences (NAS) (AAC&U, 2011; NAS, 2004, 2009). In fact, interdisciplinarity may be at the core of an undergraduate liberal education (Newell, 2010; Huber et al., 2005).

There has been a recent move in academia to increase intentionality in instruction through development of student “intended learning outcomes” (ILOs). These ILOs may be developed at multiple levels (e.g., course, program, major, etc.). Once the learning goals of the course or program have been determined, then classroom instruction can be purposefully designed to map onto those intended outcomes in a “backward design” process (Wiggins and McTighe, 2001). The ongoing challenge with any such process, however, is in determining one’s effectiveness in achieving these intended learning goals, so it is critical that efficient tools can be developed that enable these goals to

be assessed. One of the ILOs of the neuroscience program at St. Olaf College states that: “*Students will demonstrate an awareness that the scope of neuroscience necessitates an interdisciplinary perspective; they will show competence in approaching a problem using tools, symbols and paradigms from multiple disciplines.*” An important requirement of ILOs is that they are mission-driven, meaningful and parsed in such a way that they can be used to obtain evidence in a manageable way (Beld et al., 2009), but the question remains – how can we empirically assess the development of an interdisciplinary perspective in our students?

Although there have been significant increases in the amount of useful work on assessing ID learning in general (e.g., Repko, 2008b; Rhoten et al., 2006; Boix Mansilla, 2005; Field and Stowe, 2002; Stowe, 2002; Schilling, 2001; Field et al., 1994), few provide specific methods of assessment or describe clear quantitative evidence of ID learning (Lattuca et al., 2004), and little literature currently exists on empirically assessing ID learning in neuroscience courses or programs (e.g., Nikitina, 2002). For example, Haynes and Leonard (2005) tracked the development of an ID perspective in undergraduates by interviewing students from first-year to senior year. These interviews were qualitatively analyzed for content but no quantitative analyzes were performed. Two notable exceptions to this are the Interdisciplinary Writing Assessment Profiles (IWAP; Wolfe & Haynes, 2003, see also Newell, 2006) and the Targeted Assessment Rubric for Interdisciplinary Writing (Boix Mansilla et al., 2009), which, while providing very useful empirically-grounded rubrics for assessing ID writing, are both derived from student written work significantly longer than what was available to us for assessment (e.g., the IWAP written projects averaged 55 pages in length).

One widely accepted definition of ID learning calls it a process by which “learners *integrate* information, data, techniques, tools, perspectives, concepts, and/or theories

from two or more disciplines to craft products, explain phenomena, or solve problems, in ways that would have been unlikely through single-disciplinary means” (Boix Mansilla, 2010, p.289). Although other definitions exist (see Ch.1 of Repko, 2008a, for a comprehensive discussion of ID definitions), there is strong agreement that integration is one of the essential features of ID learning.

Lattuca (2001) suggests that the degree of integration of an ID teaching or research product could be assessed by examining the process, the product, or the question. Thus, we endeavored to develop simple assessment tools that use pre/post comparisons and quantitative metrics targeting the integrative aspect of ID learning. Specifically, we chose to compare two different short student products early and again at the end of the core neuroscience course in our program in an attempt to empirically assess the development of an ID perspective in our students.

## MATERIALS AND METHODS

**The Course:** *Neuro234: Introduction to Neuroscience* provides a foundation and overview of the important and extensive ways in which biological and physiological processes are involved in the regulation and maintenance of behavior. This lab course was chosen for assessment because, at the time, it was the only mandated course in the Neuroscience Concentration. Among the topics students explore are: fundamental electrophysiology, sensory and motor systems, development, integration, learning and memory. The only pre-requisite to the course was a semester of introductory biology, chemistry, psychology or physics.

The course was co-taught by a professor from the biology department (Crisp) and one from the psychology department (Muir). Both professors were present in all lectures and lab sessions, and although each lecture was prepared and delivered by one professor according to topic (see the course syllabus in Supplementary Materials), both professors participated in in-class discussions of each topic. The course also included two major writing assignments that explicitly emphasized interdisciplinarity. In the first of these (the “breadth” critical review), students wrote a paper and prepared an oral presentation based on three papers on one topic but from three different disciplines (defined by departmental affiliation of the author). In the second (the “depth” critical review) was similar, except that the three papers represented different levels of investigation (e.g., molecular, cellular, system, behavior, etc).

**The Students:** Twenty-seven students enrolled in the course in Fall 2009, including 11 sophomores, 13 juniors and three seniors; the distribution of declared majors included eight psychology, seven biology, seven chemistry and one each in nursing, math and music. Twelve students had also declared a neuroscience concentration. As a comparison group, we gave the same survey to a biopsychology course (Psychology 238). This course included 33 students: 3 sophomores, 19 juniors and 11 seniors. Of these students, 21 had declared a psychology

major, 5 biology, 2 physics, 2 math and 0 chemistry. Seven had declared a neuroscience concentration. Ten students from this course took the survey during week 7.

**Interdisciplinary Learning Assessment:** Three types of evidence were obtained for analysis:

First, students wrote in class for 10 minutes in response to the open-ended question “*What is neuroscience?*” at the beginning (Week 1) and then again at the end of the semester (Week 15). Students were not notified there would be a Post-test condition. These hand-written responses were transcribed and analyzed for changes in use of disciplinary and interdisciplinary concepts and terminology from Pre- to Post-test in individual students.

Second, students anonymously completed an online *term-discipline relevance survey* in which they indicated all disciplinary perspectives (biology, chemistry, math/computer science, neuroscience, physics, psychology, and “don’t know”) to which 41 terms (such as electrode, taste, dx/dt) were relevant. This survey was adapted from a metric developed to measure “integratedness” in a combined biology/chemistry curriculum (Abdella et al., 2011), although these authors only analyzed the number of boxes checked. Starting with the previously published survey, terms were added and removed by six neuroscience faculty from the biology and psychology departments, and an effort was made to include some terms relevant (in the eyes of the faculty) to each discipline. The survey was completed once early in the semester (Week 5) and once at the end (Week 15). A smaller set of students from this course ( $n = 11$ ) completed the survey again two years later. See Appendix for the list of disciplines and survey terms employed. About 30% of the terms overlap with the Abdella et al. (2011) survey; the discipline “math” was changed to “math/computer science” and the discipline “neuroscience” was added.

Finally, students completed the *Research on the Integrated Science Curriculum (RISC) survey* at the beginning and end of the term.

St. Olaf College IRB approval was obtained for all assessment employed in this study.

## RESULTS

### “What is Neuroscience?”

Written responses to the open-ended question “What is neuroscience?” were analyzed from 25 students who completed the 10-minute timed task at both week 1 and week 15. Results showed that students used significantly more words in their week 15 responses (mean  $\pm$  sd = 61.0  $\pm$  21.5) than in week 1 responses (39.3  $\pm$  19.1,  $t(24) = -3.69$ ,  $p=0.001$ , 2-tailed). While this change could be interpreted as an increase in the amount of knowledge regarding neuroscience available to students for their responses at week 15, more detailed analysis was conducted on students’ responses to determine how the content of their responses differed from weeks 1 to 15.

First, student responses were analyzed for explicit mentions of disciplines (as defined in relation to St. Olaf College departments, including terms using disciplinary

word stems, e.g., "Chemi", "Biology"). Ten students on week 1 and 14 on week 15 mentioned disciplines in their answers; and the total number of disciplinary mentions increased 55% (from 22 disciplinary mentions in week 1 to 34 on week 15). This suggests an increase in student understanding of the breadth of the field of neuroscience and examination of responses for individual disciplines supports this. For example, Chemistry was only mentioned by four students at week 1, but was mentioned by 12 students on week 15 – more than the number of mentions for either psychology or biology at week 15. Similarly, physics was not present at all during week 1, but was mentioned by four students at week 15. While the number of students mentioning biology and psychology showed little change over time (week 1: bio=6; psych=7; week 15: bio=7, psych=8), it is noteworthy that 68% of the week 1 disciplinary mentions were of those two disciplines. This suggests that the observed lack of change may be because students initially considered those disciplines more central to neuroscience as the course was being taught by professors from those two departments.

Student responses were then analyzed for the occurrence of specific terms related to interdisciplinarity, complexity, or integration of knowledge (Table 1; asterisks indicate a decrease). To determine whether the greater number of these word instances at week 15 (n=87) than week 1 (n=38) was not simply due to the greater number of total words in the week 15 responses, the ratio of these combined word instances to the total number of words was computed for each student's week 1 and week 15 responses. A log transform was then performed on the ratios to correct for the resulting skewed distributions. Results showed a significantly greater ratio of instances of these specific terms at week 15 than week 1 ( $t(24) = -3.20$ ,  $p = 0.004$ , 2-tailed).

	Week 1	Week 15
Behavior	4	15
Change	0	3
Circuit	0	8
*Combin-	2	1
Complex	0	2
Everything	1	7
Integrat-	0	2
*Interact-	8	7
Interdisciplinary	0	2
Multiple disciplines	0	3
System-	23	35
Transform-	0	2
* indicates a decrease in instances		

Table 1. Number of Interdisciplinary/Integrative/Complexity term/word stem instances for terms included in analysis.

As a further result of this content analysis, several other terms emerged that indicate some interesting changes in student responses from week 1 to week 15 (see table in Appendix B), but were not included in the above analysis because, although of note, it was felt they did not adequately reflect the category of interdisciplinary knowledge we were attempting to capture.

Qualitatively, the changes in many students' answers

also reflected a broader, more interdisciplinary view of neuroscience after the course and an increased understanding of its complexity. For example, one student called neuroscience "a cross between biology and psychology" on week 1, but said that neuroscience is "a very wide field that branches across a whole host of departments including biology, psychology, chemistry and physics" on week 15. Another, student at week 1 wrote "Neuroscience is the study of the nervous system and the process underlying various behaviors and biological responses. It's a really cool field that's kind of a cross between biology and psychology." But at week 15, neuroscience has become much more interdisciplinary and complex - "... there are varying levels of exploration of neuroscience. One can look at the molecular and/or cellular basis of behaviors, or a larger-scale systems approach can be applied." Finally, one student's week 15 response simply began with "What isn't neuroscience?"

### Term-Discipline Relevance Survey.

Of the 25 students who completed the neuroscience course, 20 students completed the term-discipline relevance survey during week 5 and 22 students completed it during week 15. As students completed these surveys anonymously, changes in individual students could not be determined; but changes in the group's perceived relevance of these terms to disciplines was quantitatively assessed.

On week 5, students checked  $42.18 \pm 2.36\%$  of the 287 possible boxes (each of which related a term to a discipline or "don't know"), which increased to  $48.07 \pm 2.49\%$  on week 15 and  $52.87 \pm 2.02\%$  2 years after the course. Across all terms, the reported relatedness of terms was highly correlated between week 5 and week 15 (adjusted  $R^2 = 0.92$ ;  $p < 0.001$ ; see Figure 1).

The average relevance ratings (defined as the percent of students who checked a particular term as relevant) increased across all disciplines, but to different degrees (Figure 2). For example, terms increased an average of  $9.12 \pm 1.90\%$  in reported relevance to neuroscience but only  $2.05 \pm 1.78\%$  in relevance to chemistry. We analyzed these changes using a one-way analysis of variance (ANOVA) with discipline as the categorical predictor and change (week 15 – week 5) in percent of students marking a term as relevant to that discipline as the dependent variable. (We did not conduct an analysis of within-subject changes as all of the survey data was collected anonymously and without identifiers, and changes in the data from an individual respondent could not be compared.) This analysis revealed a significant effect of discipline on increase in term relevance ( $F_{6,280} = 4.06$ ;  $p < 0.001$ ); a Fisher least squared difference (LSD) test confirmed that biology, math/computer science (cs), physics, psychology and neuroscience were all statistically different from changes in the "don't know" category ( $p < 0.05$ ). Furthermore, neuroscience and physics were statistically different from chemistry, which was not statistically different from "don't know."

Interestingly, students' ratings of relevance of a term to one discipline often correlated with their rating of relevance

of the same term to another discipline. For example, term relevance to psychology was positively correlated with term relevance to neuroscience (Pearson product-moment coefficient  $R = 0.31$ ), but was inversely correlated with term relevance to chemistry ( $R = -0.68$ ). Table 2 shows these relationships at week 5.

A pattern of term relevance relationships also emerges when disciplines are plotted as a tree diagram using a

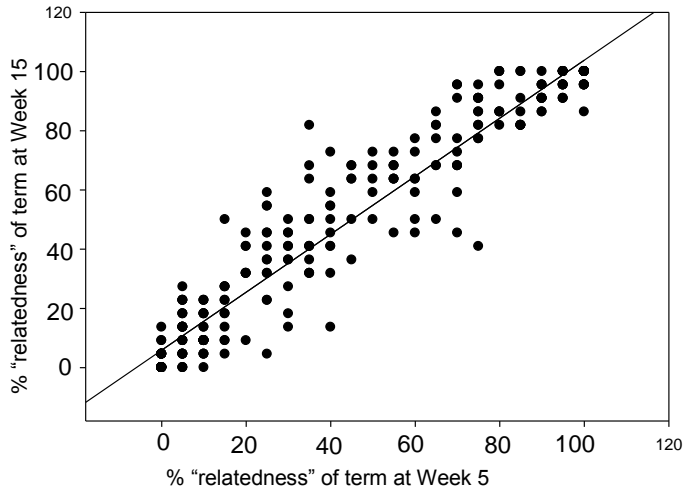


Figure 1. Student responses regarding the “relatedness” of a term to disciplines during week 5 were highly correlated with their responses during week 15 (adjusted  $R^2=0.92$ ;  $p<0.001$ ). Responses were fit using the linear model  $y = 0.9793x + 5.9251$ . Each point represents the percent of students that related one term to a particular discipline. Some points (such as 0,0) overlap.

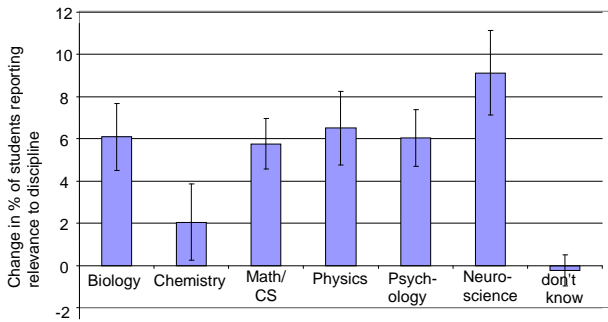


Figure 2. Gains in relevance by discipline.

	Biology	Chemistry	Math/CS	Physics	Psychology	Neuroscience
Biology	1.00					
Chemistry	0.28	1.00				
Math/CS	-0.23	0.13	1.00			
Physics	<b>-0.42</b>	0.13	<b>0.72</b>	1.00		
Psychology	-0.15	<b>-0.68</b>	-0.14	-0.25	1.00	
Neuroscience	0.27	-0.16	-0.12	-0.17	<b>0.31</b>	1.00
Don't Know	<b>-0.32</b>	-0.03	0.00	-0.05	-0.12	<b>-0.48</b>

Table 2. Term-discipline relevance correlation matrix for week 5 (bolded terms are significant at  $p<0.05$ ).

single linkage amalgamation rule and normalized Euclidean distances (Figure 3). This pattern is similar to the correlations in Table 2, except that psychology and neuroscience are distant in the tree diagram. Only minor changes in this tree diagram were observed by week 15 (Figure 3) or even two years following the course (see Supplementary Materials). The pattern of relationships that emerges when using this type of tool seems to be sensitive to both the term list that is used and the class in which the survey is delivered. For example, we asked students in a biopsychology course (see Methods) to take our survey during week 7 of their semester, and the clusters that emerged from a similar analysis included a math/cs and physics cluster, a neuroscience and psychology cluster, and a chemistry and biology cluster (Figure 4). Furthermore, when tree clustering analysis was applied to the dataset from Abdella et al. (2011), the term relevance relationships that emerged showed some differences depending on whether the survey was completed by an introductory chemistry class or an introductory biology class (see Supplemental Materials).

The pattern of term-discipline relatedness was better reflected by a K-means cluster analysis that grouped terms into three clusters according to the pattern of students’ responses for each term across disciplines. The first cluster was characterized by high term relevance to psychology and neuroscience, and low relevance to chemistry; it included: *consciousness, visual illusions, animal behavior, reaction time, mental imagery, networks, reflexes, language and brain*. The second cluster was characterized by high ratings for relevance to biology, chemistry, and neuroscience, but low relevance to psychology; it included: *sequencing, electrodes, ions, enzymes, pH, calcium, cells, voltage-gated channels, properties of molecules, second messenger, lipid bilayer, stem cell research, genetic mutations, protein structure, homeostasis, diffusion, taste, neurotransmitter, ATP and equilibrium*. The third cluster was characterized by moderate term relevance to all disciplines but low relevance to psychology; it included: *spectroscopy, modeling, logarithm, radio-isotopes, dissociation constant, electrical potential, electromagnetic spectrum, Nernst equation, Ohm’s law, dx/dt, properties of sound and exponential growth/decay*. The biopsychology class data yielded similar clusters; term-cluster membership was 85%

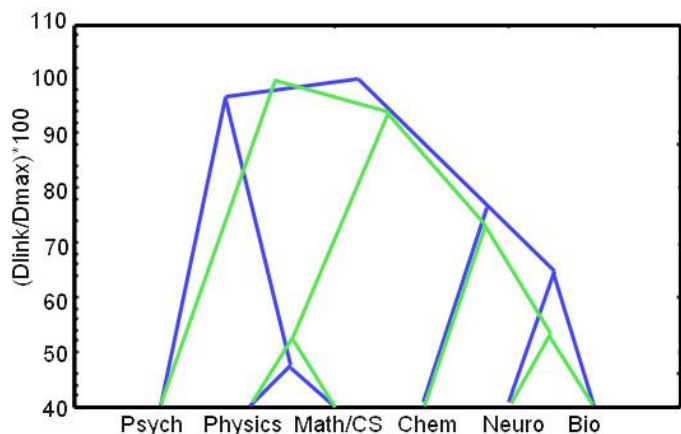


Figure 3. Tree diagram of term relevance by discipline when survey was completed by the neuroscience class. Week 5 term relevance is shown in blue, week 15 data are shown in green.

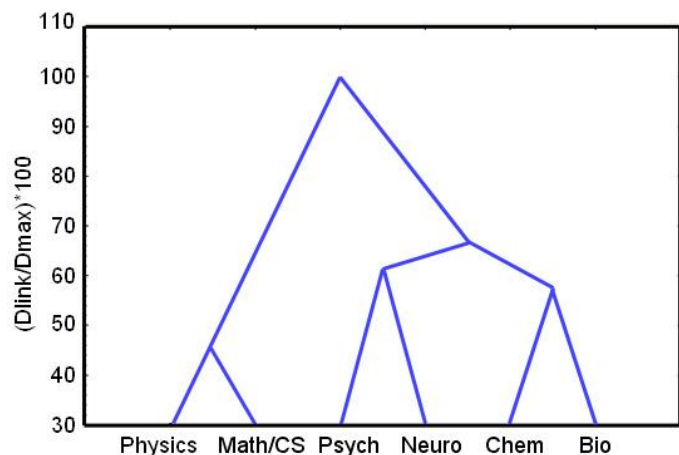


Figure 4. Tree diagram of term relevance by discipline when survey was completed by the biopsychology class (week 7).

identical with the neuroscience class at week 5, and 80% identical at week 15 (see Supplemental Materials).

Term relatedness patterns in the neuroscience class changed after the semester in interesting ways (see Table 3; boxes indicate correlations that changed in significance from week 1). For example, the correlation between biology and chemistry strengthened and became significantly correlated, as did biology and neuroscience. The correlation between psychology and neuroscience strengthened, and the inverse correlation between biology and physics weakened and became statistically non-significant. K-means cluster analysis on week 15 data revealed that just under 10% of terms switched clusters. Students now reported *electrodes*, *taste* and *neurotransmitters* as 41% (averaged change) more relevant to psychology so that these terms clustered with the first cluster (along with terms like consciousness and animal behavior). *Equilibrium*, on the other hand, now

rated 51% more relevant to physics and clustered with other third cluster terms, such as *spectroscopy* and *logarithm*.

The pattern of inter-relatedness between disciplines was preserved in the responses of students two years after the course, except that in these late responses, the inverse correlations between physics and psychology, and between psychology and “I don’t know” became statistically significant (Table 4). Cluster membership of individual terms continued to change over time than the discipline correlation pattern; after two years, *homeostasis*, and *spectroscopy* changed clusters (to the first and second clusters, respectively).

Possibly, these changes reflect the effect of further coursework completed after the neuroscience course. For example, the most common class year (mode) at St. Olaf is first-year for introductory chemistry and psychology, sophomore for introductory biology and junior for physics (St. Olaf College registrar, personal communication). At the time the survey was completed, most of the students in the neuroscience class were in their sophomore or junior year.

### RISC Survey

Data were obtained from 20 students for the pre-test and 12 students for the post-test. In summary, results showed that students reported large gains across most items examined. Students reported an average gain of 3.45 across the 48 items tested with 81% of the items receiving rating gains of greater than 3 on a 5 point scale (where 1=“no or very small gain”; 5=“very large gain”). The items specifically targeting Interdisciplinary Learning were among those for which students reported large gains (e.g., “Read primary literature from multiple fields of study”, Gain = 3.75; “Integrate ideas from two or more sciences in problem solving”, Gain = 3.67).

### DISCUSSION

Here we have described two simple instruments that generate a large and rich data set for both quantitative and qualitative analysis of ID learning in a neuroscience course. Analysis of data from these instruments showed evidence of development of an interdisciplinary perspective in students from the beginning to the end of the course. Inherent in that change in perspective, by the end of the course students see neuroscience as a more complex and integrated field. This change was reflected explicitly in their responses to the question “What is Neuroscience?”, but also implicitly, in their responses to the survey. The survey data suggests that after the course, the students now saw changes in the inter-relatedness of disciplines; for example, the positive correlation between biology and neuroscience became statistically significant, while the inverse correlation between biology and physics became statistically non-significant (see Table 4). Furthermore, these new relationships could still be observed in survey data collected two years after the course (see Table 4). The Term-Discipline Relevance Survey is an extremely flexible tool that could be adapted to assessing changes in

perspective in any area simply by changing the terms included in the survey to be consistent with the goals of the specific course or program.

We experimented with different means of analyzing the results from the Term-Discipline Relevance Survey. The tree-clustering method is an interesting way to visualize term-discipline relevance patterns that seems to be quite sensitive to the particular cohort of students and/or the course in which they complete the survey. For example, the tree pattern looked strikingly different when we gave our survey in the neuroscience course than it did when we gave it in the biopsychology course. At the same time, the tree pattern showed only minor changes across time points within our neuroscience class. The correlation matrix was also affected by the cohort and/or course in which the survey was completed. For instance, the correlation between psychology and neuroscience was statistically significant early in the semester in both the neuroscience and biopsychology course ( $p < 0.05$ ), but the  $R^2$  was 0.31 in the neuroscience course and 0.77 in the biopsychology class (see Supplementary Materials). However, the correlation matrix also showed changes in term-discipline relevance patterns within the neuroscience class cohort that could be detected at week 15, and were still apparent two years later (see Tables 3 and 4). Possibly, the tree cluster analysis is revealing something about the cognitive framework in which students (in a particular class and at a particular time) conceive of the relationships between disciplinary content domains. But, being a multi-dimensional analysis, the tree cluster analysis may not be sufficiently sensitive to correlations between individual terms and disciplines to reveal significant changes in that perspective over time. On the other hand, the term-level analysis (term-cluster membership) showed the most variability across classes and time points, and this data may be too noisy to track changes in interdisciplinary perspective over time. For example, our students may have associated the term *equilibrium* with chemistry after taking introductory chemistry as freshmen, with biology after taking introductory biology as sophomores, and with physics after completing introductory physics as juniors. Thus, we suggest that the linear correlation matrix is a useful tool for analyzing Term-Discipline Relevance Survey data when assessing development of an interdisciplinary

perspective.

It is important to note that the pedagogies used in any course or program will have a critical influence on success in achieving intended learning outcomes, regardless of how one chooses to assess them. It is therefore important to acknowledge that the team teaching nature of the course may have had an impact on the ID learning outcomes as team teaching has been identified as a pedagogy that can facilitate ID learning (Krometis et al. 2011; Little and Hoel, 2011; Wentworth & Davis, 2002). End-of-course student evaluations clearly supported this notion as students frequently commented on the benefits they perceived in interdisciplinary understanding from the team-taught format of the course.

Assessment of ID learning itself requires a multifaceted and interdisciplinary approach. "The hope for one single measure that will make our case is inappropriate for programs that embrace complexity and ambiguity as part of their core identity." (Schilling, 2001, p.353). Examples of such assessment techniques, Schilling suggests, include portfolios, structured interviews, free writing and ethnographic studies. Consistent with this approach, it is the goal of AAC&U's Valid Assessment of Learning in Undergraduate Education (VALUE) project (part of the Liberal Education and America's Promise initiative) to facilitate assessment of student learning based on authentic evidence - evidence collected as a part of students' required courses rather than external standardized tests - using a variety of such instrument types (Rhodes, 2009). One method used to collect authentic evidence of essential learning outcomes is rubrics and a number are currently available on the VALUE program website (<http://www.aacu.org/value/index.cfm>).

Overall, it is important to remember that assessment is not a single event, but a continuous cycle of planning and identifying teaching goals, collecting and sharing evidence, evaluating evidence, and implementing changes to planning based on that evidence (Miller, 2007; Maki, 2004). While we have attempted to assess ID learning at the course level using multiple instruments here, future assessment efforts will attempt to employ these instruments to examine changes at the program level with the using instruments and others, such as the VALUE "Integrative and Applied Learning" rubric.

	Biology	Chemistry	Math/CS	Physics	Psychology	Neuroscience
Biology	1.00					
Chemistry	<b>0.36</b>	1.00				
Math/CS	-0.27	0.13	1.00			
Physics	-0.38	0.26	<b>0.73</b>	1.00		
Psychology	-0.09	<b>-0.68</b>	-0.12	-0.27	1.00	
Neuroscience	<b>0.40</b>	-0.14	<b>-0.32</b>	-0.28	<b>0.42</b>	1.00
Don't Know	<b>-0.46</b>	-0.13	0.27	0.10	-0.04	<b>-0.56</b>

Table 3. Term-discipline relevance correlation matrix for week 15 (bolded coefficients are significant at  $p < 0.05$ ; boxes indicate correlations that changed in significance from week 5).

	Biology	Chemistry	Math/CS	Physics	Psychology	Neuroscience
Biology	1.00					
Chemistry	<b>0.59</b>	1.00				
Math/CS	-0.17	0.00	1.00			
Physics	-0.25	0.25	<b>0.65</b>	1.00		
Psychology	0.03	<b>-0.52</b>	-0.24	<b>-0.36</b>	1.00	
Neuroscience	<b>0.42</b>	0.04	<b>-0.42</b>	-0.22	<b>0.56</b>	1.00
Don't Know	<b>-0.47</b>	-0.28	0.25	0.09	<b>-0.40</b>	<b>-0.62</b>

Table 4. Term-discipline relevance correlation matrix for year 2 (bolded coefficients are significant at  $p < 0.05$ ; boxes indicate correlations that changed in significance from week 5).

## REFERENCES

- Abdella BRJ, Walczak MM, Kandl KA, Schweinfus JJ (2011) Integrated chemistry and biology for first-year college students. *J Chem Educ* 88:1257-1263
- Association of American Colleges and Universities (2011) What works in facilitating interdisciplinary learning in science and mathematics. Washington DC: Association of American Colleges and Universities
- Beld J, Walczak M, Gross D (2009) Engaging faculty in department level assessment. AAC&U Engaging Departments Institute. Retrieved from [www.teaglefoundation.org/.../pdf/Beld\\_departmentlevel%20assessment.pdf](http://www.teaglefoundation.org/.../pdf/Beld_departmentlevel%20assessment.pdf)
- Boix Mansilla, V (2010) Learning to synthesize: toward an epistemological foundation for interdisciplinary learning. In *Oxford handbook for interdisciplinarity* (Frodeman R et al., eds). Cambridge: Oxford University Press.
- Boix Mansilla, V (2005) Assessing student work at disciplinary crossroads. *Change* 37:14-21.
- Boix Mansilla V, Dawes Duraisingh E, Wolfe CR, Haynes C (2009) Target assessment rubric: an empirically grounded rubric for interdisciplinary writing. *J Higher Educ* 80:334-353.
- Field M, Lee R, Field ML (1994) Assessing interdisciplinary learning. In *Interdisciplinary studies today* (Thompson Klein J and Dory WG, eds). San Francisco, CA: Jossey-Bass.
- Field M, Stowe D (2002) Transforming interdisciplinary teaching and learning through assessment. In *Innovations in interdisciplinary teaching* (Haynes C ed). Westport, CT: American Council on Education/The Oryx Press.
- Haynes C, Leonard JB (2010) From surprise parties to mapmaking: undergraduate journeys toward interdisciplinary understanding. *J Higher Educ* 81:645-666.
- Huber MT, Hutchings P, Gale R (2005) Integrative learning for liberal education. *Peer Rev* 7:4-7.
- Krometis LH, Clark EP, Gonzales V, Leslie ME (2011) The "death" of disciplines: development of a team-taught course to provide an interdisciplinary perspective for first-year students. *College Teaching* 59:73-78.
- Lattuca LR (2001) *Creating interdisciplinarity: interdisciplinary research and teaching among college and university faculty*. Nashville, TN: Vanderbilt University Press.
- Lattuca LR, Voigt LJ, Fath KQ (2004) Does interdisciplinarity promote learning? Theoretical support and researchable questions. *The Review of Higher Education* 28:23-48.
- Little A, Hoel A (2011) Interdisciplinary team teaching: an effective method to transform student attitudes. *Journal of Effective Teaching* 11:36-44.
- Maki, PL (2004) *Assessing for learning: building a sustainable commitment across the institution*. Sterling, VA: Stylus Publishing.
- Miller, R (2007) *Assessment in cycles of improvement: faculty designs for essential learning outcomes*. Washington, DC: Association of American Colleges and Universities.
- National Academy of Sciences (2004) *Facilitating interdisciplinary research*. Washington DC: National Academies Press.
- National Academy of Sciences (2009) *A new biology for the 21<sup>st</sup> century*. Washington DC: National Academies Press.
- Newell WH (2010) Undergraduate general education. In *Oxford handbook for interdisciplinarity* (Frodeman R et al., eds). Cambridge: Oxford University Press.
- Newell WH (2006) Interdisciplinary integration by undergraduates. *Issues in Integrative Studies* 24:89-111.
- Nikitina S (2002) "Navigating the disciplinary fault lines" in science and in the classroom: undergraduate neuroscience classroom in mind, brain, and behavior at Harvard. *Issues in Integrative Studies* 20:27-44.
- Repko AF (2008a) *Interdisciplinary research: process and theory*. Thousand Oaks, CA: Sage.
- Repko AF (2008b) Assessing interdisciplinary learning outcomes. *Academic Exchange Quarterly*, 12:171-178.
- Rhodes T (2009) The VALUE project overview. *Peer Rev* 11:3.
- Rhoten D, Boix Mansilla V, Chun M, Thompson Klein J (2006) *Interdisciplinary education at liberal arts institutions*. Teagle Foundation White Paper.
- Schilling K (2001) Interdisciplinary assessment for interdisciplinary programs. In *Reinventing ourselves: Interdisciplinary education, collaborative learning, and experimentation in higher education* (Smith BL and McCann J, eds). Boston, MA: Anker Publishing.
- Snyder SH (1985). *Neuroscience: an integrative discipline*. In *Neuroscience* (Abelson PH et al., eds). Washington, DC: American Association for the Advancement of Science.
- Stowe DE (2002) Interdisciplinary program assessment. *Issues in Integrative Studies* 20:77-101.
- Wentworth J, Davis JR (2002) Enhancing interdisciplinarity through team teaching. In *Innovations in interdisciplinary teaching* (Haynes C, ed). Westport, CT: American Council on Education/The Oryx Press.
- Wiggins G, McTigue J (2001) *Understanding by design*. Englewood Cliffs, NJ: Prentice Hall.
- Wolfe CR, Haynes C (2003) Interdisciplinary writing assessment profiles. *Issues in Integrative Studies* 21:126-169.

**APPENDIX A. List of Survey Terms Used**

- DNA Sequencing
- Spectroscopy
- Using equations to model natural phenomena
- Electrodes
- Logarithm
- Ions
- Radioisotopes
- Consciousness
- Enzymes
- Visual Illusions
- pH
- Animal Behavior
- Calcium
- Dissociation Constant
- Cells
- Electrical Potential
- Reaction (Response) Time
- Voltage-Gated Channels
- Properties of Molecules
- Mental Imagery
- Genetic Mutations
- Reflexes
- ATP
- Exponential Growth/Decay
- Equilibrium
- Language
- Brain
- Lipid Bilayer
- Networks
- Stem Cell Research
- Homeostasis
- Electromagnetic Spectrum
- Nernst Equation
- Ohm's Law
- Diffusion
- Taste
- Neurotransmitter
- dx/dt
- Properties of Sound
- Protein Structure
- Second Messenger

**List of Disciplines used:**

- Biology
- Chemistry
- Math/Computer Science
- Neuroscience
- Physics
- Psychology
- Don't Know

**APPENDIX B. Number of Term/word Stem Instances for Other Terms of Interest**

	<u>Week 1</u>	<u>Week 15</u>
Animal	2	4
*Brain	30	27
Cell-	5	7
Control	2	9
Discipline	0	4
Environment	2	5
Experience	0	3
Field	2	8
*Function-	13	10
How	22	30
Information	1	3
Life	0	3
Mechanism	0	4
Molecular	1	5
Neural/Neuron	12	23
Neuroscience	21	36
Organism	1	5
Sensory	2	9
Structure	1	5
Understand	3	6
* indicates a decrease in instances		

Received August 16, 2011; revised October 27, 2011; accepted November 17, 2011.

The authors thank Dr. Katie Ziegler-Graham for statistics advice, Dr. Jeremy Loebach for useful discussions, Dr. Mary Walczak for sharing the raw data from the survey conducted in Abdella et al. (2011), and HHMI for their support. We also thank Drs. Whitney Schlegel, Trish Ferrett, Joanne Stewart, Graham Peaslee, Mark Levandoski, Paul Jackson, Jim Russo, James Swartz, and Vida Praitis for useful discussions as part of the HHMI Interdisciplinary Learning group that helped advance this project.

Address correspondence to: Dr. Kevin Crisp, Biology Department & Neuroscience Program, St. Olaf College, 1520 St. Olaf Ave., Northfield, MN 55057. Email: [crisp@stolaf.edu](mailto:crisp@stolaf.edu)