The BRAID: Experiments in Stitching Together Disciplines at a Big Ten University

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Abstract

Since 2005 we have pursued a formal research program called the BRAID (Bringing Relationships Alive through Interdisciplinary Discourse), which is designed to develop and test strategies for training first- and second-year undergraduate science students to bridge scientific disciplines. The BRAID's ongoing multiyear investigation points to preliminary conclusions about what does and does not promote student interdisciplinary thinking. Perhaps not surprisingly, our research suggested the most effective technique for helping introductory students see science in integrated terms has been the most direct: explicitly discussing and engaging in debate about the connections found in the real world in a seminar setting. On the other hand, adding a thin gilding of interdisciplinarity to existing courses accomplishes little. Our goal is not to devise the "ideal" interdisciplinary educational experience, but one that is efficient and sustainable in a wide range of existing curricular structures. We are particularly sensitive to the need to avoid creating eclectic models dependent on our particular institutional setting.

The case for interdisciplinary science education

It is tempting—and on some level appropriate—for students to think of science as a vast intellectual Wal-Mart. Over here you find the products of the chemical bond, over there the products of cell physiology, all ready for application to human problems and needs (including getting into a desirable graduate or professional program). You can shop science for suitable knowledge and skills, much as you might throw a pair of shoes, a tub of ice cream, and a bike tire in your shopping cart. College itself often inadvertently strengthens this view of science by stacking up facts and techniques within the discrete mental aisles of individual courses and discrete disciplines.

And students do not always appreciate the diverse selection. A chemistry major might not wish to participate in a big shopping expedition, or see the need for it. General education or major requirements thrust a shopping list in her hands that pushes her reluctantly into aisles with "soft" courses like biology and, worse, "irrelevant" ones in the humanities and the social sciences. Her goal here is to bargain hunt: to grab the prize grade with the minimal expenditure of work and thought, and to pour the savings into her "real" courses. The compartmentalization of tertiary science education allows—indeed, frequently rewards—such narrowly expedient attitudes.

Science educators aspire, for both professional and civic reasons, to educate broadly, yet our aspirations to inspire creativity, flexibility, and inquisitiveness crash against what we produce. What our students learn, or do not learn, is a much less elevated reality, as a steady stream of blue-ribbon reports has lamented for the past twenty years (AAAS, 1990; NRC, 1997, 2003; NSF, 1996; Project Kaleidoscope, 1991). One result is the production of too many science graduates with an indifferent grasp of deeper critical and integrative skills. Another is the leaky pipeline by which students leave science programs altogether, a loss of talent that is particularly severe among women and students of color (Seymour & Hewitt, 1997).

Another recent, high-profile reform effort captures the widespread consensus that undergraduate science education must become more interdisciplinary. *Scientific Foundations for Future Physicians* is a call to action from the Association of American Medical Colleges and the Howard Hughes Medical Institute, driven by acute concerns that the typical premedical curriculum, which has remained largely stagnant for decades, no longer adequately prepares students for medical practice (AAMC-HHMI, 2009). The report insists that colleges and universities should phase out checklists of prerequisite premed courses and redirect students towards the mastery of a core (but not static) set of science competencies: "emphasis should be on defined areas of knowledge, scientific concepts, and skills rather than on specific courses or disciplines." In other words, the time has come to deemphasize sequences of isolated disciplinary prerequisites in favor of interdisciplinary and integrative science education. These principles apply generally, since we want not only our doctors but also our industrial chemists, research geneticists, civil engineers, computer programmers, and multitude of other science professionals to be curious, broadly literate, intellectually flexible, and teamwork-orientated.

It is a bracing vision. But its implementation is beset by daunting practical challenges (Henderson & Dancy, 2007). We cannot simply educate generalists, and teaching specialized scientific knowledge and skills is an unavoidably intricate and time-consuming process. The chemistry student who subtly (or perhaps not so subtly) resents her time sequestered in a biology lab is not necessarily being lazy or irrational, given the extensive demands of mastering her core subject. And her chemistry professors are not necessarily indifferent to her broader educational needs when they resist shoehorning "interdisciplinary" content into a syllabus already packed to the point of bursting. *The Scientific Foundations for Future Physicians* (p. 3) explicitly called for "an integrated, nondepartmental approach" to science education, but making this a reality on any given campus cuts against an array of interests (both legitimate and parochial) (Henderson, et al., 2007). The institutional structures built around discipline-specific departments and courses might be more antiquated than venerable, but they are generally solid. This is not to say we should despair of their renovation, but rather that we should acknowledge that most blueprints for interdisciplinary teaching reform will become yellowed and dusty before they are put into practice if they have to wait on foundational curricular and departmental reorganizations.

The study

Our educational laboratory is Lyman Briggs College, an undergraduate residential program at Michigan State University devoted to studying the natural sciences and their impact on society. Such residential colleges have been shown to have positive impact on student success and retention (Pascarella et al., 1994; Pike, 1999; Pike et al., 1997; Stassen, 2003). Lyman Briggs is unique in that it is organized on interdisciplinary principles, with teaching faculty drawn from a wide spectrum of disciplines in STEM and the history, philosophy, and sociology (HPS) of science. Individually, the authors of this article are a biologist (Luckie), a chemist (Sweeder), and a historian of science (Bellon). The authors have offices within fifty yards of each other, a fact that not only provides practical benefits for collaboration but also reflects the social integration of distinct disciplines in our college. But, even though Briggs controls its introductory offerings, the freedom to innovate is still constrained by the structure of the university curriculum. Some universities create "learning communities" by allowing students to block enroll in classes; ours does not. We are locked into offering introductory physics, chemistry, biology and calculus along the university's track (Henderson et al., 2007). And, of course, the perpetual need to manage classroom space and faculty teaching schedules severely complicates reform. The BRAID project can develop and test interdisciplinary reforms in a congenial environment, but not one so idiosyncratic that the results are not readily transferable to other settings.

Methodology

Our research group has tested a variety of teaching models (explained below, Table 1) in an attempt to gather data and identify what works well to support each student's learning. Each pedagogical model sought to engage students in a practice of viewing topics from a variety of perspectives and to help each of them build their ability to see the world in a more interdisciplinary fashion. We assessed the impact of these different models of an interwoven curriculum on student learning using course evaluation, views about science surveys (VASS), embedded course content exams, expert panel interviews (as described in Wright et al 1998) and longitudinal tracking of performance in upper division courses.

Using an individual responsive interview protocol (H.J. Rubin & I.S. Rubin, 2005) administered at the end of the year, students reflected upon their experience within the previous semester, with the number of students participating in the interviews varying depending on the experimental model. This approach helped us develop a more comprehensive phenomenological picture of the student experience (Marton, 1981). Assessment of the "high-dose" model involved seven students completing experiential interviews with two external interviewers. Each interviewer interviewed three or four students individually to conduct a responsive interview (H. J. Rubin & I. S. Rubin, 2005). The interviewers took field notes and recorded each interview on a digital audio recorder that was then transcribed into manuscript format. The responsive interview protocol is essential in allowing the interviewer to participate in a structured conversation with each participant. This method provides the ability to better manage continuity, allows for clarification of meaning and understanding, and allows for the incorporation of narrative responses within the interview (H. J. Rubin, et al., 2005).

Eight students from the "high dose" model also completed faculty-generated content-based interviews in the method of Wright, et al. (Wright et al., 1998). Each student from the test group had a "matched control" student who had not completed the BRAID seminar but who also completed the content-based interview. Students were matched based on the classes taken, grades received in the courses and incoming composite ACT scores. The interviewers were unaware of whether the students were in the experimental or control groups. The interviewers took field notes and recorded each interview on a digital audio recorder which was then transcribed into manuscript format.

The models

In the preliminary stage of the BRAID we tested three basic models for balancing depth

Model	Key Features	Student Response	N	Semesters
Low Dose	Small connections between all freshman classes	Indifferent, with limited gains†	1200	6
Lab Model: (single student)	Lab reports bridged biology and chemistry (required co-enrollment of students)	Very positive*	5	2
Lab Model: (joint groups)	Groups comprised of both biology and chemistry students	Generally positive, but mix of freshman and sophomore caused issues in some groups*	8	1
Lab Model: (Hire a Chemist)	Biology student research groups "contract" with students in chemistry to collect data	Generally positive, but not all students appreciated the connections†	350	2
High dose	Students met for weekly discussions with three faculty	Very positive, being outside of "standard" class was beneficial*	29	2

* Data from interviews from all students
† Data from interviews with select students and end of course assessment survey

Table 1: Summary of interdisciplinary models tested

and breadth in introductory courses: (i) our so called "low dose" model of adding a "pinch of" connections to every freshman course across the curriculum, (ii) our "lab" model weaving the classroom laboratories of various introductory science courses together, and most recently (iii) our "high dose" model of creating a small seminar class that focused on discussing links between disciplines (Table 1). Although the idea of using a seminar class to help students connect to the sciences is not new (AAUW, 1994; Gilmer, 2007; Jesse, 2006; Kulis et al., 2002; Pell, 1996; Preston, 2004; Xu, 2008), this application is unique. Our experiences of trying to BRAID together the disciplines have provided us with one clear lesson: attempts to span the disciplines are most effective from the student perspective when the activity is explicit, is required, and involves multiple faculty members. A similar effort with three faculty co-teaching different fields of Engineering was reported recently in the Journal of STEM Education (Cox et al., 2009).

Low dose model

Over the course of three years we managed to implement many small connections between classes. These involved assignments—such as describing the chemistry in end-of-semester projects presented at a college-wide research symposium, which highlighted course content overlap between multiple courses and even class projects—that required students to find inspiration in another class (such as using calculus to model the amount of a drug present in a biological system at any time after an initial dose).

We discovered that these subtle intellectual and methodological links were generally lost on the students. When students were interviewed after the completion of their courses, they struggled to identify conceptual overlaps between the courses. Once prompted, they were able to recall the activities and could then parrot back the associations. But they clearly lacked either the inclination or the confidence to create a spontaneous map of scientific relationships. As one student responded to questions about whether they recalled connections between different disciplines (or courses) from their freshmen year:

> *Umm, kind of, has, what is a discipline? Stem cell are an example, people are against it. Kinda like, well, like, everything ingested in your body has some chemical formula, like reacts with cells, which is biological. If you inject water in cells eventually they'll burst. That was a question on my final exam in Chemistry.*

The common themes and methods that bridge the disciplines seem likely to remain largely opaque to the neophyte when presented within the environment of only one classroom. The majority of students, who are likely struggling to master the "content" of each individual course, lack the expertise to construct a strong network of intra-discipline understanding while simultaneously weaving together classes and disciplines. We concluded that activities must have the explicit primary goal of creating cross-disciplinary connections in order to help the students gain this ability.

Lab model

The three variations of this model provided a striking example of the value of *explicitness*. It appeared critical that multiple faculty members were involved in the experience, as students tend to cater their work to the perceived abilities of the instructors to evaluate their work (i.e., only the biology mattered if only a biology professor was evaluating the work). However, these models either suffered from limited enrollment/ applicability (the first two versions) or difficulty in exporting them to other educational settings (the third model.)

Yet the benefit for the students in these models can be very clear. For example, in the first model, we asked students concurrently enrolled in general chemistry and cell and molecular biology to include explicit chemical components in their independent biology lab project. A single final lab report counted towards both course grades. Historically, Briggs biology professors have been frustrated by the too-exclusive focus on biological explanations in students' lab reports. The students in this "lab model" experiment provided an accurate description of the chemistry relevant to the biology lab activities and as a result wrote, on average, much more coherent reports. One of the freshman participants later said her subsequent bio lab reports included chemistry as a matter of course. When asked why, she simply stated: "it makes more sense to include both." Years later, she pointed to this lab as a transformative experience that inspired her to leave the premed track to pursue a PhD in physiology.

High dose model

The most recent experiment in which we have had the time to fully analyze the data involved nine freshmen students. We convinced them to co-enroll in general chemistry, cell and molecular biology, and an introduction to history, philosophy and sociology of science (HPS) (Figure 1). The content and organization of these three traditional courses changed little. While leading undergraduates to a broadened, interconnected outlook, one must still keep in mind the value of specialization within a single area of science—there is a genuine value in maintaining some of the integrity of traditional discipline-specific approaches. Based on our previous experiments, we created a seminar class meeting which *explicitly* highlighted and then applied the content overlap and *involved multiple faculty.* We introduced the seminar like this: "This semester we invite you to treat science as more than a detached collection of useful things. Science ceases to be science and instead becomes suffocating dogma when it is learned in this way. Science offers a means for organizing and acting rationally upon our experiences of the physical world, which is so much greater than the sum of its parts. That is its great strength—and the strength we want you to acquire by strengthening your critical thinking skills." The students often chose the subjects for each hour-long weekly discussion. The topics, drawn mostly from current events, integrated biology, chemistry, and HPS. This "high-dose" approach had similar advantages to "learning communities" where students take a block set of courses together (Gabelnick et al., 1990; Shapiro and Levine, 1999).

This lower-stress environment allowed students to share their own ideas and (perhaps equally importantly) to join faculty from different disciplines in debate. Our exploration of global warming, for example, integrated the chemical and biological aspects of carbon sequestration to climate systems with the political, cultural, and economic realities of human behavior. As it happened, our distinct areas of expertise allowed our conversation with the students to map onto the structure of the Intergovernmental

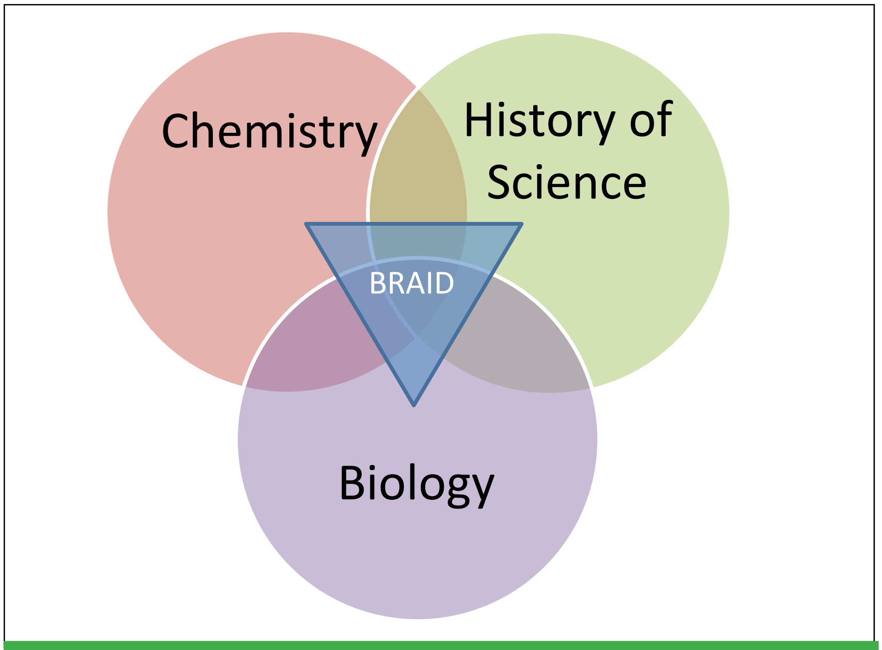

Figure 1: Model of "High Dose" Braid

Panel on Climate Change, which is currently organized into three Working Groups: The Physical Science Basis of Climate Change; Climate Change Impacts, Adaptation, and Vulnerability; and Mitigation of Climate Change (IPCC, 2007).

As one student said during a reflective interview, the best aspect of the BRAID seminar was:

> *"Well it was with the connections because sometimes they're really hard to see when you're just in your separate classes. You don't really think about the HPS aspect of chemistry or something like that or the biological aspect but with those discussions we got to pick a topic and then see each way that it connects with different things. Then since you see those connections now then you can go to class and then you can also start making connections by yourself."*

Five other interviewees expressed a similar observation. Only one of the nine students indicated that she felt that she would have been able to recognize similar overlaps without the class. These statements perhaps shed light on the inability of the students in our original experiments to identify connections between their courses. Students seem to identify all activities within a specific course as falling exclusively in that singular discipline. This suggests that changing the student mindset requires *multiple faculty members* in the classroom to represent multiple disciplines.

Our data indicate that low-prep, low-stakes activities help propel students away from the typical view of scientific disciplines as monolithic. The students then were able to at least recognize and discuss the cross-disciplinary elements that already existed within their individual courses. As one student said:

> *"so it was just like wow, like everything—it was like almost weird sometimes 'cause it would be like the same day we'd be doing like the same thing. So that was kind of cool 'cause it was like, 'Oh, yeah, like I already learned this,' or we would have been already talking about Watson & Crick in HPS for a while and then Professor [X] would talk—introducing DNA he kind of like went through a brief thing about it, and we were like, 'Oh, yeah, well, we just learned that.'"*

Students in the "high dose" BRAID model were not just a self-selected elite. The incoming ACT scores of this group ranged from 19–31 with students more heavily located at the higher end. Of the 29 students who participated in the high dose model, their GPAs ranged from 2.05–4.0 with the average being 3.44. For comparison, the average GPA of our regular freshman chemistry II class is 3.41 and the GPA range is from 1.29–4.0 (n=308).

Students in both the "high dose" and the "lab" experiments responded positively. However, they also simultaneously demonstrated concern that they may be deprived of a piece of the traditional curriculum (as students habitually imagine material "covered" in class as learned). Most of the students in the "lab" experiment voluntarily completed all of the chemistry lab modules, even though the project explicitly invited them to opt out of an assignment of their choice. This suggests that students see interdisciplinary activities as a supplement to the existing science curriculum, and not as a different (and superior) way to approach it.

Discussion

Our experiences in the "high dose" and "lab" models strongly imply the importance of being explicit and the need for the presence of faculty from at least two different disciplines to break students from mono-discipline thinking. A single instructor appears to offer only a single perspective since students typically associate faculty members with their disciplines. The students gained insight from something they otherwise rarely see: two or more academics addressing a problem unscripted. A student saw it this way:

> *"They all viewed things very differently. The one day we were discussing–there was—it was during the energy crisis, and we—we got onto the topic of voting, and how we elect representatives, and Professor [X] was—he takes a very down to earth view. And Professor [Y] uses lots of metaphors. And Professor [Z] is very opinionated. So the three of them just clash often. And they clash all the time."*

The multiple faculty model allows students to participate in a genuinely interdisciplinary conversation, but we must take care that they do not interpret "view[ing] things very differently" as confrontation. Science professionals invariably work in teams: fostering interdisciplinary habits of mind includes an introduction to the social norms necessary for pooling knowledge and expertise (AAMC-HHMI, 2009). If students interpret the sharing of different perspectives as somehow antagonistic, many will be less eager to contribute their ideas, for fear of giving offense, and less agreeable to the interventions of colleagues from other disciplines.

The multiple faculty model also addresses another potentially critical factor in any scaling-up process: faculty comfort. Instructors can bring their specialist expertise to complex real-world topics without the obligation to (appear to) master all its aspects. A discussion of, say, global warming can move into the technicalities of topics like the carbon cycle, ecosystem function, and externalities in economic markets without getting bogged down in them. Team teaching also allows instructors to shed the "sage on the stage" persona which students too often expect (and get).

In our seminar, the rotation of lesson planning helped minimize prep time. This structure also provided liberation from the traditional class with its sense that a certain amount of content must be "covered," because the focus of the seminar was on a process, not on content. The flexible format allowed students and faculty to engage freely in the definition and solution of problems. It also allowed students to interact closely with faculty, an important aspect in college success (Astin, 1984; Strong, 2009).

It is important that instructors find these seminars to be both low-maintenance and intellectually enlivening. We recognize that faculty skepticism is a hurdle to interdisciplinary teaching reforms. The leap from recognition of the need for reform to concrete action is not trivial, especially given the abundant demands on an instructor's time. We recognize that our innovations will not prove sustainable if they add significantly to faculty workload or demand substantial resources from administrators. It requires considerable planning to make dramatic changes to an existing syllabus. Our seminar model encourages incremental improvement to the core introductory courses, yet it does not demand time-intensive overhaul.

Although most of our residential college faculty try to use research-informed teaching practices, there is still the constant pressure to fall back on the standard lecture format in order to "cover" course content. One of our subordinate goals is to help faculty gain comfort with student-centered teaching strategies. We anticipate that the smaller scale of the seminar course, along with the rare opportunity to co-teach, will increase faculty expertise in inquiry driven teaching methods, which they can import into their regular courses. Research into faculty experiences (Evans & Chauvin, 1993; B. Keller et al., 1999; B. A. Keller & Russell, 1997) will be critical during the upcoming scale-up stage to determine whether this is a more broadly feasible approach and whether faculty change is realized.

Conclusion

While it is not uncommon for students to eventually notice overlap between some content of their upper–level courses, we strive for both an earlier and a cross-disciplinary "aha" moment with our freshmen. We want students to more facilely bring these larger conceptual chunks of understanding into working memory as they strive to tackle new problems. For example, a student who understands a protein as a large "molecule" is better equipped to draw upon chemical concepts like intermolecular forces and bond polarity for understanding cellular mechanics. The chain of mutation, to altered amino-acid sequence and to different protein function, then becomes easier to grasp. This application of basic chemical principles allows students in turn to generate more mature hypotheses in their biological course. They do not simply know "extra": they know it more productively and learn it more efficiently.

It is instructive to remember that students can fall into the same depth vs. breadth concerns that faculty often express when considering curricular innovations. The authors of *Scientific Foundations for Future Physicians* anticipate that "achieving economies of time spent on science instruction would be facilitated by breaking down barriers among departments and fostering interdisciplinary approaches to science education." Pursuing this laudable goal requires attention not only to pedagogical design, but also to reorienting student expectations of what a scientific education should look like.

The overarching plan of our project is to build a sustainable "braided" curriculum and learning community at the introductory level and to test whether this helps students develop the conceptual frameworks they need to gain higher-level cognitive skills over time. We continue to assess the impact of different models on student learning; surveys (Halloun & Hestenes, 1998), embedded course content exams, expert panel interviews (Wright, et al., 1998) and longitudinal tracking of performance in upper-division courses (Rauschenberger & Sweeder, 2010; Sevenair et al., 1987; Turner & Lindsay, 2003) throughout the rest of the students' undergraduate career are ongoing.

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References

AAAS. (1990). *The Liberal Art of Science*. Washington, D.C.: American Association for the Advancement of Science.

AAMC-HHMI. (2009). *Association of American Medical Colleges and the Howard Hughes Medical Institute, Report of Scientific Foundations for Future Physicians Committee.* Washington, DC: Association of American Medical Colleges.

AAUW. (1994). Shortchanging Girls, Shortchanging America: A nationwide poll that assesses self-esteem, educational experiences, interest in math and science, and career aspirations of girls and boys ages 9–15: Executive Summary. Washington, D. C.: American Association of University Women.

Astin, A. W. (1984). Student Involvement—A Developmental Theory For Higher-Education. *Journal Of College Student Development, 25*(4), 297–308.

Cox, M. F., Berry, C. A., & Smith, K. A. (2009). Development of a Leadership, Policy, and Change course for Science, Technology, Engineering, and Mathematics graduate students. *Journal of STEM Education: Innovations and Research, 10*(2), 9–16 .

Evans, L., & Chauvin, S. (1993). Faculty developers as change facilitators: The concerns-based adoption model. *To Improve the Academy, 12*, 165–178.

Gabelnick, F., Macgregor, J., Matthews, R.S., and Smith, B.L. (1990). Learning communities: Creating connections among students, faculty, and disciplines. San Francisco: Jossey-Bass.

Gilmer, T. C. (2007). An understanding of the improved grades, retention and graduation rates of STEM majors at the academic investment in math and science (AIMS) program of Bowling Green State University (BGSU). *Journal of STEM Education: Innovations and Research, 8*(1), 11–21.

Halloun, I. A., & Hestenes, D. (1998). Interpreting VASS dimensions and profiles. *Science & Education, 7*(6), 553–577.

Henderson, C., & Dancy, M. H. (2007). Barriers to the use of research-based instructional strategies: The influence of both individual and situational characteristics. *Physical Review Special Topics-Physics Education Research, 3*(2), 1–14.

IPCC. (2007). *Synthesis report. Contribution of Working Groups I, II and III to the Fourth Assessment*. Geneva: Intergovernmental Panel on Climate Change.

Jesse, J. K. (2006). Redesigning science: Recent scholarship on cultural change, gender, and diversity. *Bioscience, 56*(10), 831–838.

Keller, B., Russell, C., & Thompson, H. (1999). A large-scale study clarifying the roles of the TI-92 and instructional format on student success in calculus. *International Journal of Computer Algebra in Mathematics Education, 6*(3), 191.

Keller, B. A., & Russell, C. A. (1997). Effects of the TI-92 on calculus students solving symbolic problems. *International Journal of Computer Algebra in Mathematics Education, 4*(1), 77.

Kulis, S., Sicotte, D., & Collins, S. (2002). More than a pipeline problem: Labor supply constraints and gender stratification across academic science disciplines. *Research in Higher Education, 43*(6), 657–690.

Lyman Briggs College from lbc.msu.edu accessed May 2011.

Marton, F. (1981). Phenomenography—describing conceptions fo the world around us. *Instructional Science, 10*(2), 177—200.

NRC. (1997). *Science teaching reconsidered*. Report by Advisory Committee to NSF-Directorate for Education and Human Resources, Washington, D.C.: National Research Council.

NRC. (2003). Bio 2010: *Transforming undergraduate education for future research biologists*. Report by Advisory Committee to NSF- Directorate for Education and Human Resources, Washington DC: National Research Council.

NSF. (1996). *Shaping the future: New expectations for undergraduate education in science, mathematics, engineering, and technology*. Washington, D.C.: National Science Foundation.

Pascarella, E. T., Terenzini, P. T., & Blimling, G. S. (1994). The impact of residential life on students. In C. Schroeder & P. Mable (Eds.), *Realizing the educational potential of residence halls* (pp. 22–52). San Francisco: Jossey-Bass.

Pell, A. N. (1996). Fixing the leaky pipeline; Women scientists in academia. *Journal of Animal Science, 74*, 2843–2848.

Pike, G. R. (1999). The effects of residential learning communities and traditional residential living arrangements on educational gains during the first year of college. *Journal Of College Student Development, 40*(3), 269–284.

Pike, G. R., Schroeder, C. C., & Berry, T. R. (1997). Enhancing the educational impact of residence halls: The relationship between residential learning communities and first-year college experiences and persistence. *Journal of College Student Development, 38*(6), 609–621.

Preston, A. E. (2004). *Leaving science:* Occupational exit from science careers. New York: Russell Sage Foundation.

Project Kaleidoscope. (1991). *What works: building natural science communities* (Vol. 1). Washington, D.C.: Stamats Communications, Inc.

Rauschenberger, M. M., & Sweeder, R. D. (2010). Gender performance differences in biochemistry. *Biochemistry and Molecular Biology Education, 38*(6), 380–384

Rubin, H. J., & Rubin, I. S. (2005). *Qualitative interviewing: The art of hearing data* (2nd ed.). Thousand Oaks, CA: Sage.

Sevenair, J. P., Carmichael-Jr., J. W., O'Connor, S. E., & Hunter, J. T. (1987). *Predictors of organic chemistry grades for Black Americans* (No. ED286974): Xavier University of Louisiana.

Seymour, E., & Hewitt, M. (1997). *Talking about leaving.* Boulder, CO: Westview Press.

Shapiro, N., and Levine, J. (1999). Creating learning communities: A practical guide to winning support, organizing for change, and implementing programs. San Francisco: Jossey-Bass.

Stassen, M. L. A. (2003). Student outcomes: The impact of varying living-learning community models. *Research In Higher Education, 44*(5), 581–613.

Strong, P. E. (2009). *College students and faculty in the residential college environment: An investigation of student development in the designed living-learning environment.* Saarbrücken: VDM Verlag Dr. Müller.

Turner, R. C., & Lindsay, H. A. (2003). Gender differences in cognitive and noncognitive factors related to achievement in organic chemistry. *Journal of Chemical Education, 80*(5), 563–568.

Wright, J. C., Millar, S. B., Kosciuk, S. A., Penberthy, D. L., Williams, P. H., & Wampold, B. E. (1998). A novel strategy for assessing the effects of curriculum reform on student competence. *Journal Of Chemical Education, 75*(8), 986–992.

Xu, Y. J. (2008). Gender disparity in STEM disciplines: A study of faculty attrition and turnover intentions. *Research in Higher Education, 49*, 607–624.

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