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ABSTRACT

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Symbiosis on Campus: Collaborations of Scientists and Science Educators

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Abstract

This symposium will provide insights into collaborations among scientists and science educators in a variety of contexts – large research universities, small state and private institutions, and collaborations involving both pre-service and in-service programs. The session will begin with a brief framing of these collaborations as management of the ecosystem of teacher education, followed by overviews of the experiences and perspectives of the panelists. The bulk of the session will be an interactive forum for dialog about the costs and benefits of collaboration, the theoretical groundings for such collaborations and how such collaborations fit into and might influence the larger system of science education. Participants will also be invited to share their experiences in collaboration, and to collaborate further by sharing descriptions of these collaborations on the World Wide Web. A site with descriptions of involved collaborations is posted on the web at http://www.people.cornell.edu/pages/dad55/ScienceEdCollab.htm. The paper for the session is also available on the site.

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Symbiosis on Campus: Collaborations of Scientists and Science Educators

Problem: coordinating niches in the ecosystem of science teacher preparation

Don Duggan-Haas, Cornell University

> Organisms within their individual lifetimes and in the course of their evolution as a species do not adapt to environments; they construct them. They are not simply objects of the laws of nature, altering themselves to bend to the inevitable, but active subjects transforming nature according to its laws.
>
> (Lewontin, 1982, p. 163)

All of the panelists for this symposium are active in the process of reshaping the niches they fill in their educational ecosystems. This is happening by forming new and hopefully mutually beneficial symbiotic relationships, by undergoing individual metamorphoses, and by carving out new dimensions of our own niches and the niches of those with whom we work. We engage in ecological disturbance, and disturbances in complex systems have five qualitatively different kinds of outcomes:

- The system can continue to operate as before, even though its operations may be initially and temporarily unsettled.
- The system can operate at a different level using the same structures it originally had (for example, a reduction or increase in species numbers).
- Some new structures can emerge in the system that replace or augment existing structures (for example, new species or paths in the food web).
- A new ecosystem, made up of quite different structures, can emerge.
- The final, and very rare possibility, is that the ecosystem can collapse completely and no regeneration occurs.

(Kay & Schneider, 1994)

These ideas taken from ecological research seem to parallel the possibilities in interventions in educational systems. According to Kay and Schneider, we cannot accurately predict which of these five kinds of outcomes will happen. Further they argue that we should not attempt to manage for some particular outcome, but rather acknowledge that, "… We must instead recognize that ecosystems represent a balance, an optimum point of operation, and this balancing is constantly changing to suit a changing environment." We can't manage ecosystems and we can't truly manage learning. We can, however, manage our interactions with ecosystems and with learners. This symposium discussed how we manage those interactions (and we and our colleagues in the sciences are included amongst the learners).

Science teacher education programs have two central parts: science coursework and education coursework. Even though students in teacher education programs take the lion's share of credit hours in a science department, faculty members and the general public tend to think that teacher preparation is the domain of Colleges of Education. Most states now require that future science teachers have the equivalent of a science major. In the 1999-2000 school year, teachers who completed a science major taught 80% of high school and 49% of middle school science courses (Seastrom, Gruber, Henke, McGrath, & Cohen, 2002)[1].

We expect K-12 science teachers to teach utilizing inquiry, but generally they have not been taught science that way (Duggan-Haas, 1998; Salish, 1997). There is valid criticism of both the science and education parts of these programs, and all too often, students are left to their own devices to integrate the disparate pieces of their teacher education programs. We need a more ecological approach to teacher education (Wideen, Mayer-Smith, & Moon, 1998).

Through collaborations of scientists and educators, we may design programs (or professional learning systems (Hoban, 2002)) that are more integrative and less a collection of parts. This symposium ties directly to the conference theme of "Excellence in Science Teaching for All," as at the core of all these collaborations is the drive to improve science teaching for K-16 students, future teachers and practicing teachers. These collaborations aim for more positive symbiotic relationships among scientists, educators, pre-service and in-service teachers and K-16 students.

Through a more cohesive and explicit relationship among scientists and educators, preservice and inservice programs can be made part of a coherent professional learning system; an approach that recognizes the educational system as a complex adaptive system (Hoban, 2002) or, to use the phraseology of NSF, a complex educational system.

Structure of the symposium and paper

The symposium will begin with panelists describing cases of collaboration at their individual sites. The kinds of collaborations and the kinds of institutions vary. Presenters include scientists, science educators and a scientist morphing into a science educator. The panelists have experience in teacher education and science programs at large research universities, and small state and private institutions. Experiences include both pre-service and in-service programs for teachers and college science teaching more generally.

Each panelist will briefly describe his or her experiences and perspectives on scientist/science educator collaborations. The bulk of the session will be devoted to a discussion among panelists and audience members, beginning with the discussion questions at the conclusion of the paper.

Perspectives on, and stories of, collaboration

The effect of collaboration: Learning together toward the development of the mutualistic science educator of the future

Hedy Moscovici* & Brendan McNulty* California State University – Dominguez Hills

[1] Unfortunately, teachers often teach science courses in a science other than their academic major.

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This study focuses on the collaborative efforts between a science teacher educator (Moscovici) and a science faculty (McNulty) during a professional development institute for science teachers that centered on inquiry and literacy. Seen from a professional development perspective, the collaboration evolved in a positive direction due to the following elements:

1. Length of the collaboration (Garet, Porter, Desinone, Birman, & Yoon, 2001).
2. Focus on academic subject matter (Garet et al, 2001; Crowter & Cannon, 2001; Wilson, 2002; Pyle, 2002; Govett & Hemler, 2002)
3. "Hands-on" opportunities and integration into daily practices (Garet et al, 2001; Guskey, 2002)
4. Collaborators belong to all areas involved in science education (Gilmer, Hahn, & Spaid, 2002; Thompson & Gummer, 2002; Henderson & Lederman, 2002)

But the most important of all,

5. All collaborators are experts and novices in various situations and roles alternate smoothly during the collaborative effort. Collaboration needs to be a two-way ticket and all collaborators need to learn during the experience. That is why mutualism is the most productive and beneficiary metaphor for collaborative efforts between, in this case, a science educator and an earth scientist.

Learning – The Research Scientist

"Are you excited about the subject? Interested to find out more?" These were the questions asked by Dr. McNulty, a talented research scientist who worked with us for the last three years. He was asking the participants who were looking for patterns in earthquake data if they thought they had come up with some ideas. Earthquake locations and magnitudes, as well as frequencies, were puzzling the teachers. Which parameter was the most important? Of course, the discussion of the data set led to a discussion of plate tectonics, the unifying theme of modern geology. Of key importance here however was the fact that the teacher participants were ready for reading, writing, listening, and debating while learning about the plate tectonics. Clearly, their curiosity was piqued through discussion of the observed-earthquake data. Teacher participants were temporarily transformed into research scientists analyzing data and learning from published materials, experts, and peers. At the same time, the research scientist learned that the best way to teach is to intrigue and challenge the audience. As he stated, he now thinks of teaching in a new light and will try to excite the students first in order to spark their interest, engage their curiosity and build their passion for earth science.

Learning – The Science Educator

Moving from Earth Science as memorizing a collection of rocks and minerals for the college earth science test to trying to understand the earth and beyond was a journey that took Dr. Moscovici over 20 years. During Dr. McNulty's engaging examples and learning in a text-rich, technology-rich atmosphere, earth sciences came to life. Plates moved, volcanoes erupted, earthquakes took place, and the face of earth changed constantly over time. It is interesting to try to read the past and predict the future using only the present while also building the alphabet. As a biologist, it reminds me of trying to understand genetics or evolution.

Why is collaborators' relationship of mutualism important for the success of the professional development?

Learning – The Teachers Participating in the Institute

Following the summer part of the institute we provided the teacher participants with a survey where they had to provide ratings as well as three examples for their learning of science, literacy techniques and pedagogy. On a Likert scale from 1 to 5 with 5 being the highest "agree," the 35 teacher participants who took the survey rated their learning of science concepts that they would use in the future at an average of 4.46. They rated their learning of literacy techniques to be used in the future at an average of 4.71, and their learning of pedagogy (that was not explicit) to be transferred in their classrooms at an average of 4.42. Examples for the sciences came from very general science ideas such as energy, earth science, genetics, to very specific examples such as study of earthquake data, the Coriolis effect, and Drosophila melanogaster (fruit flies) in genetic research. Examples of literacy techniques that are applicable to science included KWL-plus, concept maps, double-entry journal writing, and techniques to summarize, compare/contrast, and become active readers. From a pedagogical perspective, memorable topics included the idea of "inquiry science," giving students choices, the application of pre-post testing, more active involvement of students in assessing their own learning, the use of multiple intelligences, and English Language Learners techniques during science teaching and learning.

Evolution of a Scientist Becoming a Science Educator: Collaboration Within Science and Science Education

Penny J. Gilmer, Florida State University

Gilmer's experiences are described in detail in Appendix A. That appendix is a standalone paper. The abstract of that paper is as follows:

> This is part of action research project in which I studied my own university-level, Web-enhanced, biochemistry classroom. I am a scientist who strives to improve the learning environment in my university classrooms.
>
> I compare four themes from within this biochemistry classroom with the same themes in my own life in order to understand why they are important to me. These themes are technology, collaboration, autonomy, and relevance.
>
> In this paper I focus more on the collaboration theme, since that is the focus for the symposium (Duggan-Haas, Moscovici, McNolty, Gilmer, Eick and Wilson, 2003; session 12A) on "Symbiosis on Campus: Collaborations of Scientists and Science Educators," at the 2003 annual meeting of the National Association for Research in Science Teaching. By understanding the role of collaboration in my own life, I hope to understand its role in my teaching and in my students' learning.

Using Amateur Astronomy as a Scaffolding into Research Astronomy

John Wilson, Georgia State University

The National Science Education Standards (NSES) (National Research Council, 1996), and the American Association for the Advancement of Science (AAAS) advocate using inquiry as a major instructional component in science classes. Science for All Americans (AAAS, 1990) has a section titled "Teaching Should be Consistent with the Nature of Scientific Inquiry" (p. 200). In this section they discuss how teachers should use student teamwork to engage students in science by actively asking questions and devising experiments and/or observations that try to answer these questions. Because teachers are being encouraged to do scientific inquiry in their science classes the NSES has included professional development standards for teachers. In these standards they say, "Professional development occurs in more ways than delivery of information in the typical university course, institute, or teacher workshop ... a useful way to learn science content is to participate in research at a scientific laboratory" (p. 58). Before science teachers can do scientific inquiry with their students they should have an experiences doing scientific inquiry themselves.

Current immersion/apprenticeship programs are providing science teachers the opportunity to participate in real scientific investigations (Melear, 2000; Wilson & Lucy, 2002; Wilson, 2002; Gilmer, Hahn & Spaid, 2002). One question about these programs is how long do they need to be so that teachers have an effective experience doing science? Melear (1999) did a study in which research scientists expressed the opinion that teachers would need about two years to complete such an internship. From my experiences I think the scientists believed that it would take several months for teachers to learn about the scientific research being done at any particular lab. Then it would take several more months for the teachers to actually do some research and become contributing team members. On the other hand most science teachers said that one-year, or less, was all they could devote to being a science intern. Therefore, a strategy is needed to create a way for teachers to do authentic research with a scientist in a period of time that is reasonable for both the scientists and the teachers.

Amateur astronomers regularly do scientific research that is acceptable and useful to professional astronomers. The American Association of Variable Star Observers (AAVSO) has a long tradition of using amateur astronomers to observe variable stars. In their *Hands-on Astrophysics* (1997) program they show how anyone, including high school students, can make authentic observations and contributions to the variable star database of the AAVSO. In addition, Tanguay (1999) has shown how amateur astronomers can make authentic contributions to astronomy by observing binary stars. If observations of variable stars and binary stars can be done by anyone, then it seemed to me that teachers should be able to do amateur, yet authentic, observations as part of an astronomical research project. I decided to use amateur astronomy as a scaffold that would allow teachers who knew little, or no observational astronomy techniques, to become contributing researchers at a level that may be feasible in a time frame of one summer.

During the summer semester of 2002 I taught a Directed Studies class for teachers. As part of this course the teachers became my research team to make binary star observations for the United States Naval Observatory (USNO). I wanted to teach this class using nontraditional techniques, similar to those described by Melear (2000). Therefore, no specific textbook was required. Instead I built a Web site (Wilson, 2001) for the teachers to use throughout this course. It included amateur and professional resources specific to binary stars and some observing techniques. In addition to Web based resources, current issues of popular amateur astronomy magazines such as *Sky & Telescope* and *Astronomy* were required course materials. The teachers were also free to use any other resources they found on their own. It was felt that using these types of resources, instead of formal textbooks, would provide the teachers with a wider range of materials at an appropriate level from which to learn astronomy in general and about binary stars specifically.

During the first week of class the teachers were given a copy of an outdoor observing lab exercise, "Observing Double Stars" (Dawson, 2001). This lab was completed on the first clear night using amateur telescopes at Georgia State University's (GSU) Hard Labor Creek Observatory (HLCO). Three different double stars, Mizar & Alcor, Alberio, and ε Lyrae were selected for this first observing experience because each one had a discovery, or surprise, to be found by the teachers. Also on that night the Moon was visible in the sky and the teachers naturally wanted to look at it with the telescopes. This provided them experience pointing the telescopes and gave many of them their first look at the Moon through a telescope. Minimal directions on how to aim the telescopes were given; they were simply shown how the telescopes operated and where allowed to point them at the Moon. Once this was accomplished, I had them aim the telescopes at the optical double star, Mizar and Alcor, because it was the brightest of the three selected, and because this optical double star is relatively easy to locate in the handle of the Big Dipper. After successfully finding this pair of stars I had the teachers go to successively more difficult binary stars of Alberio, and ε Lyrae. All these activities provided scaffolding (Vygotsky, 1987) that helped the teachers to become more confident in their abilities to point a telescope.

At the next class meeting we discussed these HLCO observations and what they had seen and learned about binary stars. This discussion included how close together the binary star companions appeared to be to each other (angular separation), the orientation of the two stars relative to north (position angle), the colors of each star within the system, and finally that some binary stars are actually multiple stars with more than two stellar components. After this discussion the teachers were given a copy of Tanguay's (1999) *Sky & Telescope* article, Observing Double Stars for Fun and Science. In the article he describes how amateur astronomers can do binary star research using their own backyard telescopes. This article caused the discussion to be directed towards the types of measurements that the teachers would be making during the remainder of the summer.

The seven teachers participating in this project were divided into three small research groups. Each group was assigned the task of determining the current position angle and separation for one binary star system that was listed as neglected in the Washington Double Star Catalog (WDS). The teachers used the course web site link to USNO and the WDS. At this time they were not given any further directions, and came to me only when they experienced a problem and to get approval of their choices. Not every choice was approved because some of the groups had selected binary stars too close together to be resolved by the HLCO instrumentation, or stars that could not be observed from Georgia during the summer. After each group had selected an approved binary star to observe they obtained finding charts of the stars using the Digitized Sky Survey at Space Telescope Science Institute. At this point I had them submit a request to the United States Naval Observatory for any archival data that may exist for their binary star. USNO responded very quickly and in one case the teachers left class with an e-mail copy of the historical data for their selected binary star. At this point the teachers were interacting with USNO astronomers and myself. Their entrance into research astronomy was beginning.

Under my guidance each research group made their own observations at HLCO using a Bollar and Chivens 16-inch telescope, equipped with an Apogee AP-7 CCD camera. The three groups completed their observing programs over three different evenings at the observatory. Two groups took images on two nights and one group only obtained images on one night. The remainder of the summer was spent doing data analysis of the CCD images taken by each group.

As part of this analysis the image scale of these pictures was determined using Tanguay's (1999) list of calibration stars and also using previous calibrations done in 2001 (Wilson and Lucy, 2002; Wilson, 2002). The position angles and angular separations of all three binary stars were successfully measured.

At the end of the summer each research group presented their binary star data to an authentic audience of astronomers and submitted a written report of their observations to the United States Naval Observatory. On 1 August 2002 the astronomy faculty and graduate students at GSU hosted an afternoon seminar during which the teachers presented research poster papers. These were patterned after poster papers that astronomers typically give at professional meetings such as the American Astronomical Society's annual meetings. After the presentations several of the faculty told me that they thought these teachers had done an excellent job, considering that they knew very little astronomy at the beginning of the summer. At the end of this seminar the research papers were sent to USNO. All three papers were accepted for inclusion in the library at USNO (GSU, 2002) and the data was used to update the Washington Double Star Catalog.

Near the end of the summer I ask each teacher how making amateur observations helped him or her to make research observations? Their answers to this were:

> "It started to help me learn my way around the sky. Understanding directions, movement of stars across the night sky, and what I was trying to look for and see."

> "Making the amateur observations a couple of weeks ago helped me with the research observations because I would not have had any idea what to look for when we were looking for that first glimpse of a faint star. I would not have known to look in the direction of Vega and I also was very naïve as to the fact that we could only view certain star systems depending on the season"

> "It helped by actually getting to use a telescope and getting a feel for direction and what to look for. It was extremely helped in orienting myself with the sky and stars."

> "It was an attention grabber! It immediately got us interested in looking at objects. The experience of working with the smaller scope was similar to the experience of working with the larger scope, but it was less complicated. Therefore, it removed some of the anxiety or thoughts that it would be difficult to do/see."

> "Practice using the red "bull's eye" apparatus on the telescopes was good preparation for using the large research telescope."

From these statements it is obvious using simple backyard telescopes early in the project helped these teachers transition into using a larger more sophisticated telescope later in the summer. In addition it can be seen that this amateur observing caused them to learn additional astronomy content such as motions and directions of the celestial sphere, seasonal nature of observations, and even some star and constellation names.

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The teachers in this project seemed to have had a very meaningful experience doing research astronomy. They did make observations that were acceptable to USNO. However, just when they were ready to do several more neglected binary stars on their own, the summer abruptly ended and the project was over. So, it seems that a summer semester may be minimum length of time needed to have an experience doing an authentic science projects. Obviously more time would have been better. One of my participants suggested that doing this during a full fifteen-week semester would have been improved the experience because they felt rushed all summer long. The results of this study seem to be consistent with those of Westerlund et al. (2002) who has also studied the effectiveness of summer long research experiences for teachers.

The New Science Educator's Perspectives on Building Collaborations

Charles J. Eick, Auburn University

New professors beginning the process of collaboration face many initial hurdles in building bridges between science education and the sciences at large universities (Duggan-Haas et al., 2000). Connections often come serendipitously through ongoing or beginning projects requiring science and science education to come together. Creating, building, and maintaining these collaborations takes some "know how" that is often faced through trial and error. However, some research does exist about building and maintaining such collaborations (Spector, Strong, & King, 1996).

In one of our collaborations, we, two novice professors, have learned from this literature as well as our own experience in beginning and sustaining collaboration between two important entities on campus. Ongoing collaboration in science education first and foremost needs to mutually benefit the major parties involved – self-interest is often the modus operandi for each of us. My colleague, a professor in the Department of Fisheries, is deeply interested in aquatic science education in the K-12 arena. I, a professor in science education, am deeply interested in capitalizing on our state's greatest resource (water) and unique programs (e.g. Fisheries) as a vehicle for applied science education – or STS approaches (Bybee, 1997; Kumar & Chubin, 1999; Yager, 1995). Aquatic science education has research-based promise as a motivational tool for enhancing scientific literacy and economic opportunity in our state (Conroy & Walker, 2000; Ramsey, 1993; Roth & Lee, 2002; Siegel, 1999; Weld, 1999, Wingenbach, Gartin, & Lawrence, 1999).

Along with self-interest, collaborations (and collaborators) must bring complementary skills, talents, and knowledge together. Each member of the collaboration provides unique expertise that is needed for the collaborative effort to succeed. This expertise can be knowledge-based, such as scientific knowledge or pedagogical knowledge, but can also be personality-based such as "big picture thinking" or a "details orientation." Also, expertise in collaboration often involves professional and personal "connections" with institutions and people who can further the collaborative effort – e.g. community leaders, politicians, deans. Networking and talking with the people who are impacted by the work or can influence the collaborative effort is vital to shape and reshape the effort in more fruitful directions (Hall & Hord, 2001). In our collaboration, my partner in fisheries brings the technical knowledge, personal connections, and big picture thinking to our work. I bring the pedagogical knowledge and teaching experience that helps

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ground our efforts in what is "doable" and sustainable in schools. I provide the details needed to implement our efforts.

Partners in strong collaborations enjoy sharing and listening to each others' ideas and knowledge as much as the collaborative effort itself. Personal growth as a professional is a product of successful collaborations and helps sustain them (Spector et al., 1996). Yet, the "glue" that maintains collaboration over time is a track record of a trusting, working relationship and a strong commitment to a *clear vision* among partners (Bohen & Stiles, 1998; Lasley, Matczynski, & Williams, 1992; Spector et al., 1996). Collaborators must be as honest and upfront as possible about their ideas, roles, concerns, and potential funding issues before collaborating and during collaboration. This adherence to open but gentle honesty helps develop trust among collaborators. In addition, the collaborative effort itself must be bigger and more important to collaborators than any of its parts. Otherwise, the collaboration will not last past the project or task at hand. My partner and I have strong values and beliefs that science education should elevate one's societal and economic status in life. We believe that scientific literacy should mean more than educating one in/about science through traditional approaches that are not working in our historically disadvantaged schools (Nieto, 1996: Lynch, 2002; Rodriguez, 2001). Our personal religious backgrounds under-gird these core values and our continued collaboration.

Communication and understanding are also vital ingredients in collaborations. Time is the precious commodity needed for collaborators to meet and further their work (Duggan-Haas et al., 2000). Institutional support must be provided through release time from other obligations to devote to collaboration. This release time can come through grants or institutional commitments to the collaboration, but must be provided if the collaboration and the collaborative work are to survive without the "burnout" of its members. Communication is furthered by having a shared *culture* between partners (Spector et al., 1996). This shared culture can be rooted in education, but can also be rooted in the particular science-base underlying the collaboration. My partner and I both share an agricultural science background. This shared culture gives me a clearer understanding of applied science approaches and the work of Cooperative Extension Systems, among other things.

Ultimately, new collaborations will be marked by successes and failures depending upon the scope of the project and amount of institutional and financial support. Our collaborative thrusts may be unique in that we attempt to bridge existing institutions and programs for science education outreach without relying on the big grant monies to make this happen and sustain it. Collaborations can form to complete small tasks that take little or no money to accomplish. For example, our collaboration instituted program changes for preservice teacher education, including courses and internships in aquatic science education. However, completing larger tasks with bigger audience impact outside of the purview of what members directly control requires strong institutional commitment, and ultimately, financial support (Bohen & Stiles, 1998).

Discussion Questions for the Symposium

The tales of collaboration individually do not answer deep questions about general issues of collaboration. The discussion will delve into the collective experience with collaborations and look for patterns. The questions below will be used to open the discussion.

- What defines a successful collaboration?
- What makes a collaboration last?
- What makes one last in the absence of funding?
- How long does it take to establish collaborative relationships? Why?

- What does it take to build the relationship?
- How can faculty empathize with each other (and our students)?
- What collection of "necessary but not sufficient" elements is sufficient?
- How do we navigate cultural differences? What cultures are most important to consider?
- What's personality got to do with it?
- What roles do collaborations fill?
- What roles would they fill in a perfect world?

The Collaborative Vision for Science and Mathematics Education had many successes, but it doesn't exist anymore. Arguably, CVSME laid the groundwork for a multi-million dollar HHMI grant and several other smaller initiatives. See {Duggan-Haas, 1999 #158;Duggan-Haas, 1999 #168} for more information about CVSME. Was it's utility fulfilled by what it helped create?

Shaping our niches as our niches shape us: what are we learning from the process?

Don Duggan-Haas, Cornell University

Among the goals of the collaborations described by our panelists is better understanding the dynamics of the system. How are we doing that? What kinds of differences do we make? What are emergent properties of collaborative systems?

In many situations, people seek simple solutions to complex problems. It may appear that suggesting collaborations as a route to improving science education is one such simplification. It is just the opposite. What this suggests is complexification to address some of the complicated problems of science education.

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Appendix A:

Evolution of a Scientist Becoming a Science Educator: Collaboration Within Science and Science Education[2]

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[2] This paper was presented at the annual meeting of the National Association for Research in Science Teaching in Philadelphia, PA, on 25 March 2003, as part of a symposium on collaboration of scientists with science educators.
[3] This paper will be a portion of a doctoral thesis in Science Education at Curtin University of Technology. I earned my first doctorate in Biochemistry from the University of California, Berkeley in 1972.

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Purpose of the Study

This is part of action research project in which I studied my own university-level, Web-enhanced, biochemistry classroom. I am a scientist who strives to improve the learning environment in my university classrooms.

I compare four themes from within this biochemistry classroom with the same themes in my own life in order to understand why they are important to me. These themes are technology, collaboration, autonomy, and relevance.

In this paper I focus more on the collaboration theme, since that is the focus for the symposium (Duggan-Haas, Moscovici, McNolty, Gilmer, Eick and Wilson, 2003) on "Symbiosis on Campus: Collaborations of Scientists and Science Educators," at the 2003 annual meeting of the National Association for Research in Science Teaching. By understanding the role of collaboration in my own life, I hope to understand its role in my teaching and in my students' learning. This paper is part of a doctoral thesis in Science Education to be submitted to Curtin University of Technology.

Methodology

This is a qualitative study that investigates my collaboration with others (including colleagues and my students), using of an autobiographical point of view. In this historically constituted research I use activity theory (Engeström, 1999; Engeström, Miettinen, & Punamäki, 1999) in a search for patterns of coherence and contradictions in my autobiography and in the learning environment of my biochemistry class (Taylor, Fraser & Fisher, 1997; Elmesky, Muire, Griffiths, Taylor & Tobin, 1996).

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I use a mixed method design (Newman & Benz, 1998) with both qualitative and quantitative methodology, but with more emphasis on the qualitative. The main sources of qualitative data are from 1) students' written responses concerning collaborative learning, 2) an end-of-the-semester questionnaire on the learning environment in the classroom, 3) interviews with two students after I issued grades for the course, and 4) e-mail correspondence. I use the quantitative data from a constructivist-based learning environment survey that my students completed at the end of the semester. For the autobiography, the main sources of data are previously published writings, e-mail communication, letters, and other written documents.

I have chosen the methodology of action research (Reason & Bradbury, 2001), a way to study human interactions. I analyze my students' perceptions and perspectives (expressed in writing and orally), to improve the learning environment in my own Web-enhanced biochemistry classroom (Gilmer, 1999).

For this autobiographical study I utilize Guba and Lincoln's (1989) quality criteria, which include the parallel criteria of trustworthiness (i.e., credibility, transferability, dependability, and confirmability), the hermeneutic process, and the authenticity criteria (i.e., fairness, ontological authenticity, educative authenticity, catalytic authenticity, and tactical authenticity). In addition, I utilize the fourteen guidelines set forth by Bullough and Pinnegar (2001) for autobiographical forms of self-study designed especially for researchers who are examining their own teaching.

For this particular paper, I focus on the collaboration thread within my autobiography and how it relates to patterns of collaboration observed in my biochemistry classroom. The theoretical underpinning for this study is social constructivism (Vygotsky, 1962; Lemke, 1995; Fosnot, 1996). We construct our knowledge socially, by communicating and interacting with each other.

Reading Bruffee's book on *Collaborative Learning: Higher Education, Interdependence, and the Authority of Knowledge*, in the summer of 1997, just before teaching the biochemistry course, influenced my thinking. Bruffee (1993) emphasizes that it is critical for students planning to become part of a specific community of learners, to learn "the language in which community members construct the knowledge that is their common property" (p. 3). Bruffee states: "The job of college and university teachers is to represent the knowledge communities of which they are members in a way that will most effectively reacculturate potential new members" (p. 3). Reading Bruffee encouraged me to attempt to develop a classroom in which the primary interactions would be among my students instead of my being a "sage on the stage." My main goal was to have my students learn greatly from each other rather than me being their primary source of knowledge. In 1998, I implemented such a design in a 15-week biochemistry course. I required the students to work in small groups, and each group developed ten Web sites on a variety of topics of biochemistry (Gilmer, 1999). Through these activities, many of my students (but not all) learned what it means to work and learn collaboratively.

I include activity theory diagrams (Engeström, 1999; Engeström, Miettinen, & Punamäki, 1999) to focus on both the coherences and contradictions in moving the subjects toward their objects and the outcomes. In the first case, the activity diagram concerns my collaborations with scientists (Figure 1), and I am the subject moving toward my objects (i.e., learning biochemistry content and contributing to research) with my outcomes (i.e., becoming a professor of chemistry and biochemistry). In the second case, I am still the subject but, in this case, I am coming to learn science education in my collaborations with science educators (Figure 2). My objects include learning the culture, values, epistemologies, and methodologies of science education. My outcome will be when I finish the second doctorate in science education and become a full-fledged science educator conducting research at the interface between science and science education.

To utilize an activity theory diagram, one focuses not only on proceeding from the subjects to the objects to the outcomes, but also on looking for components that enhance the processes, like tools (or resources), communities, rules, and division of labor (Figures 1 and 2). Embedded within these categories may be factors that disempower the individual, thereby disrupting the flow of the subject toward the objects and the outcomes. In the autobiography below, there are examples of how to utilize such activity theory diagrams.

Figure 1:Interactions in Collaboratic

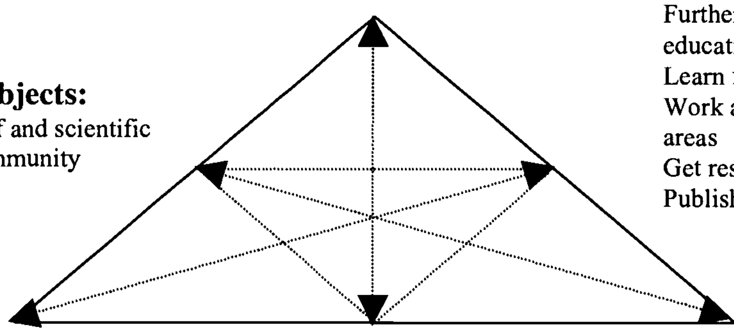
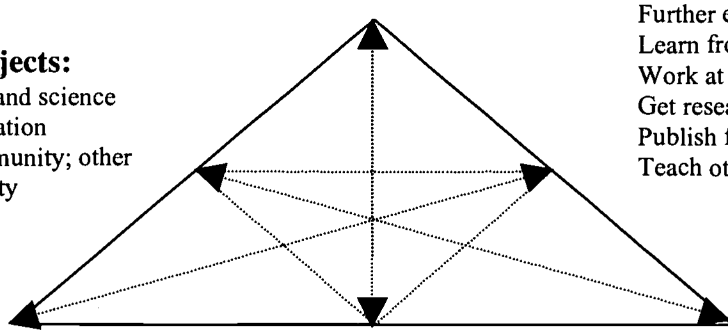


Figure 2: Interactions in Collaboration with Science Education Colleagues



Collaboration Within Autobiography

By utilizing my initial training in biochemistry, I reflect on how collaboration with other scientists and science educators has influenced my own ideas on collaboration. Each time I reflect helps me understand my own viewpoint, which, in turn, helps me to understand—and sometimes change—how I portray those ideas to my own students.

Collaboration Within Undergraduate School in Science

Reflecting back when I was an undergraduate chemistry major at a women's college, I learned chemistry within a competitive environment. Each chemistry student worked alone to make sense of chemistry. I always solved my own problem sets and wrote up my own laboratory reports. Even in laboratory each student worked individually. Since I am the sort of learner who can thrive in this sort of culture, this approach felt comfortable to me at the time. However, over time I have come to realize that this sort of culture just happened to fit my learning style and that there are many other types of learners with their own preferences for learning. There may have been other people desiring to be chemistry majors who did not become chemists because they needed the tools, or community, or rules, or division of labor (Figure 1), which would facilitate that process, thereby helping them reach their objects and outcomes.

Collaboration Within Graduate School in Science

My first experience with professional collaboration was not until I was in graduate school at the University of California, Berkeley. My graduate research involved collaboration among several scientists (see "rules" in Figure 1). In a sense I was the one who brought together the research of my two major professors in science. One of them knew how to purify the transaminase enzyme, and the other knew how to study enzyme mechanisms using fast reaction kinetics. I contributed to the collaboration through my knowledge of vitamin B6 chemistry (from my master's thesis at Bryn Mawr College). My dissertation was to determine the pH-dependence of the forward and reverse rate constants for an enzyme-catalyzed aldimine formation between the active site of the transaminase enzyme and the aldehyde form of vitamin B6.

I found that I liked working at the interfaces between scientific fields. When I needed to learn more, I had access to faculty members and to the graduate students and staff working in the different fields (see "communities" and "division of labor" in Figure 1).

Collaboration as a Postdoctoral Fellow

Collaboration became my mantra by the time I finished my doctorate. Thus, I worked with two faculty members for both of my postdoctoral fellowships at Stanford University. I worked at the interfaces between a traditional medical school discipline and chemistry. By working collaboratively with both a physiologist and a physical chemist, I was able to apply biophysical techniques (mainly electron paramagnetic resonance) to study the interaction between a class of small bioregulator molecules called prostaglandins and the human red blood cell membrane.

I stayed for a second postdoctoral fellowship at Stanford University with the same physical chemist as one of my advisors and an immunologist as the other. I learned how to isolate the outer plasma membrane from tumor "target" cells and used them to block or inhibit the recognition between a primed immune cytotoxic T cell and its tumor target. I purified the plasma membranes using biophysical techniques to separate the proteins from the other cellular membranes. Using immunoprecipitation and two-dimensional gel electrophoresis, I identified a number of the protein species on the cell surface. Again, this research would have been much harder to do without the expertise available to me through collaboration (see Figure 1 in moving from "subjects" to "objects").

There were both advantages and disadvantages to working within the type of collaborative environment that I experienced. Although I was able to contribute my understanding to important research questions that would have been unavailable to me without the collaboration, it was difficult at times to work within the culture of both a medical school and a chemistry department.

The medical school culture was extremely competitive with about a dozen graduate students and postdoctoral associates working within two small research laboratories. In our research group meetings in the medical school I felt we were pitted one against another, so instead of encouraging collaboration it fostered competition. At one point my immunologist mentor told me to "sweep" some research results "under the rug" because he did not want to incorporate such results into his thinking. I remember I felt disillusioned with science in the medical school culture by that act.

Fortunately, it was different in the chemistry research laboratory. My chemistry mentor would never have said that same comment about sweeping results under the rug. In fact, I remember my chemistry mentor saying that we were trying to find the "truth," not the truth based on pre-conceived notions. Still I bridged the two worlds of chemistry and the medical school that were physically just across the street from each other, but that were in many ways, so far apart because of the differences in cultures.

Collaboration as a Faculty Member

I have been a chemistry faculty member now for 26 years. As an assistant professor, my department chairperson, biochemistry divisional members and other colleagues in the department initially discouraged from collaborating with other scientists. . However, once I was tenured, collaboration became more open to me.

Discouraged from collaboration as an assistant professor.

During my tenure-earning years from 1977-84, I was discouraged from collaborating with others in research. The rationale for this was so that when it came time for my departmental and other university colleagues to make their decisions on my promotion and tenure, it would be easier for them to know what I had accomplished in research if I had only published without the expertise of some senior colleague. At that time there were no other research groups in my department that studied membranes or immunology. I expressed this in a correspondence written in September 1978 to the immunologist with whom I worked on my postdoctoral fellowship:

It was nice to see you again at the Gordon Conference. It was a stimulus for me as I had been out of direct contact with immunologists for my first year here other than attending the Cell-Cell Recognition meeting in San Diego last February.

Since my research program was immunochemistry of cell membranes, I felt isolated in the faculty position. However, in my second year I met the one other immunologist, a new assistant professor in the Biological Science department. Our research groups then began meeting jointly for journal club once a week for about four years.

I did try to collaborate with another Biological Science colleague and his staff on the characterization of some mammalian membranes using electron paramagnetic resonance (EPR), a method I had learned during my postdoctoral fellowship. I taught a graduate student how to spin label the membrane samples for EPR and how to analyze the complex slow motion of the spin label inserted in the membranes. However, when the graduate student wrote the manuscript for publication, all that the biology professor would do was to thank me in a line in the acknowledgments for my "technical assistance." I was furious at him for not including me as a coauthor, and I told him to remove my name from the acknowledgments. I cannot think how he would think an assistant professor would spend pre-tenure time doing "technical assistance." This incident soured me from further collaborations with him and most other faculty until I was promoted.

However, I did have one collaborative project that was positive during my years as an assistant professor. One of my biochemistry colleagues and I had a joint master's degree student. We worked in a very competitive area to isolate messenger RNA (m-RNA) that codes for the major histocompatibility complex antigens (e.g., the cell-surface recognition molecules) and to translate it into protein in a cell-free translation system. The graduate student's background was not in chemistry, so she needed to learn calculus and physical chemistry to remain in the chemistry graduate program. By the time she characterized her m-RNA, others had already published similar work. Although our work did not result in a publication, I felt better about collaboration through the interactions in this project.

Encouraged to collaborate as a tenured faculty member.

Once I was promoted and tenured in 1983, I reconnected to collaboration through an Institute for Molecular Biophysics graduate student who wanted to work on a project between our university and Oak Ridge National Laboratory about the isolation of a microorganism that could biodegrade trichloroethylene. The plan was to use monoclonal antibodies as a tool to characterize the population of microorganisms. I felt that I could contribute to the collaboration. This research did result in a publication and the student's doctoral dissertation.

Once tenured, I finally felt I could offer an interdisciplinary course similar to one I had taken as a graduate student at University of California, Berkeley, called *Social Responsibility of a Scientist.* Two Berkeley professors, one from Biochemistry, Joseph B. Neilands, and the other from Physics, C. L. Schwartz, co-taught the course in 1969. They opened my eyes to the ethical issues in science. Keynote speakers included many great scientists (including a few Nobel laureates): Owen Chamberlain, Joshua Lederberg, Spencer Klaw, Michael Scriven, Herbert Boyer, Barry Commoner, George Wald, Serge Lang, Robert Stebbins, Robert Feeney, Tom Brewer, and

Lawrence Rose. What I learned from that course lives in me. When I look at my old notes from class, and it all comes back. The course continues to bring relevance to my understanding of science.

My first foray into teaching a course similar to the one I took at Berkeley had me as the sole professor. However, while teaching *Problems in Science and Society*, I met an FSU psychology professor, Michael Rashotte, who wanted to collaborate with me and offer an interdisciplinary *Science, Technology and Society* (STS) course, maintaining the thread of ethics in science throughout the course (Gilmer & Rashotte, 1989/90). It was so refreshing to be an associate professor and to be encouraged to interact with another scientist in co-teaching a course. We received funding for this new course from our university.

When I was a tenured associate professor, I became the Interim Associate Dean of the College of Arts and Sciences. That was a time of an opening up in my academic life. I became more confident of myself, and, due to my position within the Dean's Office, many people got to know me. I began to speak out to others on how it was to be a woman in science. For instance, at a colloquium in Mathematics and Science Education in May of 1991, I spoke of ten "stepping stones" in my professional life. Concerning one of the "stones," I said:

FSU was lonely when I first came as [there were] very few women in the sciences. Margaret Menzel [from Biological Sciences] was helpful. I struggled to get published and to get grants. It had always been easy to get papers published with my doctoral or postdoctoral advisors' names on it, but it was much harder on my own. I had trouble getting tenure, but I appealed and won. It was a hard time, but I put it behind me. Within a year I even had a grant for the URP-FPE [Undergraduate Research Participation-Faculty Professional Enhancement] program with the departmental chair, who did not support my tenure decision. Still I had a hole from which I had to pull myself out, but my earlier confidence in myself helped me.

Here I remember that feeling of loneliness of being the only woman doing research for my beginning years as an assistant professor. While our department had another tenured woman faculty member who did only teaching and service with no research, I was the first woman who was on equal footing with the men. Research was the ingredient that constituted power in the department and at the university.

What significantly affected my entire career, while I was in the Dean's Office, was meeting Kenneth Tobin, who at that time was a faculty member in Science Education in the College of Education. Tobin asked me if I wanted to collaborate with him to improve teaching and learning of science at the university level. I agreed to do so. I was in a position within the Dean's Office to encourage my science colleagues to collaborate with us. I learned to reflect on the nature of science knowledge and how to teach science. Tobin later told me I was like a "breath of fresh air," as I was truly interested in collaboration.

Encouraged to collaborate with science educators.

Even though I collaborated with the psychologist in the STS class, for sixteen years I had not thought to encourage my students to collaborate within the classroom. That started to change once I began to collaborate with Ken Tobin. He encouraged a "community of learners" within our research group focused on teacher preparation in science and within his graduate classroom that I took in *Evaluation* (Tobin, 2002).

I was at that time what I would consider now to be a positivist—one who believed in empirical knowledge, and that knowledge was out there to be learned, independent of the knower. I did not even know what the word positivist meant at that time. About three years after I started to collaborate with Tobin, in a critique of the writing of a positivist for the journal, *Science and Engineering Ethics*, I defined positivism as "a system of philosophy which holds that the source of positive knowledge is facts, as elaborated and verified using the methods of the empirical sciences" (Gilmer, p. 71, 1995). By the time I wrote that critique, Tobin and I had an NSF-funded teacher preparation program in which we did educational research while working with faculty from Arts and Sciences who were teaching the science "content" courses for preservice elementary school teachers. I helped develop the team of Arts and Sciences faculty in physics, chemistry, oceanography, geology, meteorology, biological science, and philosophy.

It was at this time that I first became aware of radical constructivism, a way of thinking of knowledge as constructed by individuals rather than as knowledge that was "out there" to be learned. Tobin, Kahle, and Fraser (1990) discuss constructivism:

> Within the constructivist view, learning is defined as the acquisition of knowledge by individuals through a process of construction that occurs as sensory data are given meaning in terms of prior knowledge. Learning is always an interpretive process and always involves individuals' constructions. (pp. 6-7)

I remember in the beginning I resisted radical constructivist ideas, as it was very difficult for me as a scientist to get beyond the positivist approach I had learned and used (and had taught to others) for over 30 years since the start of my undergraduate career.

How I came to change from a positivist towards a radical constructivist and later toward a social constructivist was a slow and gradual process, which I would say is still evolving. Change was, and still is, difficult because I had developed deep-seated ideas on the nature of knowledge and the nature of science through years of practice as a student, a postdoctoral fellow and a faculty member. Such ideas do not die or change quickly. It takes rethinking everything to change one's embedded paradigms and mental constructions.

My collaboration with Tobin involved interacting with people not just in the sciences, but also in science education. We had a team of the Science Education graduate students who worked with us on our NSF-funded project. I learned with the graduate students in their preliminary examinations, prospectus defenses, and research projects. I was able to learn and use the language of science educators and experience the culture of science education because I lived in it. I could empathize with the other scientists whose classrooms we studied and could learn from them about my own teaching. Our edited book includes some chapters from what we learned from that research (Abbas, Goldsby, & Gilmer, 2002; Roth & Tobin, 2002).

The methodology for a constructivist inquiry is different than a traditional inquiry. Central to a constructivist inquiry is the hermeneutic dialectic circle, which involves multiple constructions, as one tests her ideas and gets feedback from others involved in the study or from one's peers (Guba and Lincoln, 1989). I learned some qualitative research methods, including the quality criteria for fourth generation evaluation (Guba and Lincoln, 1989) and methods of analysis of qualitative data.

I also collaborated with Angelo Collins when she was on the faculty in Science Education. She and I developed a masters degree program called Science FEAT for middle school teachers, funded by the NSF (Spiegel, Collins, & Gilmer, 1995). Although it was very difficult for me to teach 72 teachers in a situation that encouraged their reflection, it got me started. When I look back at my teaching STS to the Science FEAT teachers, at that point in 1993, I was still very much a positivist. However, the process of teaching these talented teachers and reflecting with them on learning moved me along the continuum towards being a more reflective and constructivist teacher myself. Working with them over a three-year period had a powerful effect on changing the way I teach. I saw these middle school teachers trying to improve their teaching, developing their own theories of learning, experiencing scientific research, and conducting and writing their own action research from their classrooms (Spiegel, Collins & Lappert, 1995; McDonald & Gilmer, 1997). *If the middle school teachers could improve their teaching by reflecting and doing action research, I felt I should try to do so too.* Therefore, the Science FEAT teachers became my role models.

The Science FEAT teachers taught me the power of action research (Spiegel, Collins & Lappert, 1995; McDonald & Gilmer, 1997). I had never done research in my own classroom prior to Science FEAT program. I did my first action research when I was teaching a general chemistry class for honors students in 1996 (Gilmer, 2002). Since then I have done action research and selected an area for improvement each semester to investigate my teaching and the students' learning in my own classroom.

Collaborating with Australian science educators.

In 1995, taking the *Evaluation* taught by Australian Ken Tobin was a powerful learning experience. I worked within a community of learners (Tobin, 2002) while reading Guba and Lincoln's (1989) *Fourth Generation Evaluation.* Reading Guba and Lincoln's text was very difficult for a practicing scientist, as it criticized the positivist views of science.

While taking Tobin's class, I met another Australian, Peter Taylor, a faculty member in the Science and Mathematics Education Centre (SMEC) at Curtin University of Technology. Taylor was on sabbatical at my institution, and he was the guest speaker in Tobin's course on *Evaluation*. I was attracted to Taylor's open-ended and creative ideas on teaching and learning. Taylor spoke about how one of his graduate students used his dreams to help him become a better teacher (Williams, 2002). Since dreams had been an important part of my self-understanding (Gilmer, 2002), I connected to Peter Taylor's ideas on social constructivism. In fact, Taylor's lecture triggered my "triple point" dream. The triple point is a metaphor for my developing a rapid equilibrium between my teaching, research and service, where they are interchangeable, with one becoming the other (Gilmer, 2002).

Two years later in 1997, I decided to work towards a second doctorate in Science Education with both Peter Taylor and Kenneth Tobin as my co-major professors. I spent a three-month sabbatical in Perth at Curtin University of Technology where I enrolled in a graduate course in *Constructivism* with Peter Taylor. I also worked with Taylor and Tobin as co-editors in a book, *Transforming Undergraduate Science Teaching: Social Constructivist Perspectives* (Taylor, Gilmer, & Tobin, 2002).

Glasersfeld (1993) calls constructivism "a theory of knowing rather than a theory of knowledge," and continues that "constructivism does not deny an outside world, it merely agrees with the skeptics and holds that the only world we can know is the world of our experience" (p. 24). Social constructivism differs from radical constructivism in that radical constructivism focuses on the individual constructing knowledge while social constructivism includes interactions of the learner with others to facilitate learning within a group of learners. Therefore, individuals construct ideas, but social interactions facilitate the process as students try to explain scientific ideas and learn from each other's developing ideas.

This collaborative effort of co-editing the book with Tobin and Taylor was one of the major ways I learned the background literature in social constructivism and deepened my understanding of teaching and learning (Taylor, Gilmer & Tobin, 2002). This happened early in the process of working toward my second doctorate. Critically reading each chapter and helping to frame the book contributed to my growth as a science educator. Writing the metalogues (Bateson, 1972) for each chapter of the book with my two co-major professors was particularly influential in my thinking. Writing my own chapter influenced how I think about teaching and learning and what sort of action research I do in my own classroom (Gilmer, 2002). Such collaboration was active learning and provided me with the tools to work with other scientists as they embark on a journey of conducting and interpreting action research in their own classrooms.

With time, especially in my years of learning science education from Tobin, Collins and Taylor, I experienced the power of learning from other science educators within a collaborative effort. In collaboration, one gives up some of one's own autonomy to be able to engage in the give and take of exchange of ideas. There is a tension between autonomy and collaboration. My coming to realize this tension has opened up an avenue in my classroom. This was not as clear to me earlier, when I taught the biochemistry class that was the site of action research for my doctoral study, as it is now after writing parts of my doctoral thesis in science education.

Collaboration Within Biochemistry Classroom

Designing the Biochemistry Classroom

In my biochemistry classroom, I designed an action research study with a large component of activities for the students to interact collaboratively with each other. Each collaborative group had to develop 10 Web sites on various areas of biochemistry and present 3 of them in class (Gilmer, 1999a).

Since this course was the first semester of a two-semester sequence, I felt that the students needed to learn the same material as the other section of this course taught by another faculty member during the same semester. Students within their collaborative groups had a choice of what topic to choose as long as it fit within a biochemistry chapter to be learned. For instance, one group chose complex carbohydrates for the chapter on sugars. One African American woman within that group chose to discuss the carbohydrates in sweet potatoes and the chemical that causes the yellow color in the sweet potato. She felt she had the autonomy to choose what was important for her to learn because it related to her culture. However, she was able to do it with the others in her collaborative group since the group had chosen complex carbohydrates for their theme for the Web site presentation.

However, there was another group of two women students who could not resolve this tension between autonomy and collaboration. One of the two students finished the class, and she did the "group" projects in the second half of the semester individually, without the advantages of collaboration. Instead, she experienced the hassle of trying to contact her group member without getting any response. The student who persisted in the course experienced full autonomy to choose her own Web site topic and how to develop it. In retrospect, I think that the tension between autonomy and collaboration was too strong for this pair of students. Each of these students had tried to work with different collaborative groups, but I ended up pairing them together since they did not work well in other groups.

Some of the other collaborative groups experienced at least some of this same tension between autonomy and collaboration at times. The students would try to ease the tension as they worked to complete their projects. The evidence is there in the words the group members wrote on the collaborative learning forms that I distributed on the day that Web sites were due.

The consecutive responses for Group 2's ten Web sites reflect the group members' tension between autonomy and collaboration, to the following statement, "*The skills/knowledge we have each gained working in this group are...*"

Web site 1: Working together as a group,

Web site 2: Starting to work individually,

Web site 3: Learning something by having each one working in a particular part of our topic and then combining all those things together,

Web site 4: Generating a strong cohesive Web page,

Web site 5: Developing a better ability to work together and exchanging ideas,

Web site 6: Combining prior knowledge to current topics dealing with biochemical compounds to make a Web site,

Web site 7: Incorporating questions into our Web site,

Web site 8: Suggesting to each other corrections for developing good Web pages,

Web site 9: Helping each other find links for our particular topic by email; learning to work as part of a group, and

Web site 10: Developing skills such as cooperation, patience, and productive discussions.

The tension between collaboration and autonomy is clear in each consecutive entry throughout the entire semester. Most groups moved back and forth on this tension wire between autonomy and collaboration during the semester. However, there tended to be more coherence when groups completed their Web sites on time and maintained relevant discussions, when each group member made significant contributions.

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Reflecting on Teaching Biochemistry

From the point of view of a scientist becoming a science educator, there were difficulties in trying to get the students to work collaboratively, as many of them had never had a science class in which collaboration was a necessary part of the learning. I gathered data throughout the semester, using the students' assignments, their electronic portfolios, self- and peer-evaluations of group presentations, e-mails, and interactions with my students, both in class and outside class. It is the compilation of these data from my biochemistry students, in addition to facets of my educational autobiography, on which I base my doctoral thesis in Science Education at Curtin University of Technology.

In essence, I conducted a formative assessment on the learning environment during the semester in which I taught the course. I lectured generally once a week about the key concepts within the chapter. Generally, one other per day we had student presentations of Web sites and the other day was for lessons about technology (two days a week I taught in a technology-enhanced classroom) or organizing the upcoming next set of Web sites. I realized during the semester that the students wanted me to lecture more. Even though I would have liked to change that during the semester, I felt my hands were tied, as each group had three presentations to give, for a total of 30 student-led presentations in class with 42 class meetings. I felt like the die was already cast, and I could not change my approach to teaching midstream. Originally, I had planned the course for 24 students, but we ended up with 34, as a number of students pleaded with me to be part of the experimental course. That change in class size constrained me to maintain the presentations, thereby leaving less time for my overviews of biochemistry.

During the last week of class, I asked the students to complete a questionnaire evaluating the learning environment of the class. After the semester was over and grades had been issued, I interviewed two female students from my class.

It was the constructivist-based learning environment questionnaire (LEQ) designed for college students that provided the most helpful feedback about my classroom. For the quantitative questions, I used traditional statistical measures, such as mean, standard deviation and median. Using the QSR software package for qualitative analysis, I was able to sort and analyze the students' qualitative responses. Students had answered specific questions on the Web-enhanced classroom in which the students learned biochemistry while working in collaborative groups. Analyzing both the qualitative and quantitative data gave me new insights into my students' perceptions of the learning environment.

Using such data helped me to construct a story about the classroom in which I portrayed classic four types of students I had in the classroom, and I put them all in the same collaborative group. A student, Mary, whom I had interviewed, wrote a summary of how I depicted the classroom in the fictionalized story:

The scenario depicted any group of students that worked together for the duration of the course. There is commonly a level-headed member who guides the group with confidence. One or two members of the group show strength in the course content and/or the technology of computers and the Internet. Then there is the student who is always , "so busy," and lacks

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cooperation and commitment. As I read this short story, I tried to figure out who held these characteristics in my group and members of my class.

Showing my short story[3] to students from my class is a form "member checking" (Guba & Lincoln, 1989; Polkinghorne, 1997) about the learning environment of collaborative groups within the biochemistry classroom. Students responded to the story more thoroughly than I think they would have done had I given them a more traditional educational research report to read. This type of feedback helped me to reach deeper levels of understanding about the learning environment in the classroom (Gilmer, 2000).

The interview data gave me insights into how students talked about learning biochemistry. One student, Mary, granted me a long interview just before she graduated (about six months after the biochemistry course ended), and I could get into the flow of how she spoke. I utilized how she spoke when I wrote a fictionalized account of the students trying to collaborate in my biochemistry classroom. The day before I interviewed Mary I had given her a copy of a paper I had presented on the portfolios that four pre-service teachers in our class had kept on their goals throughout the course (Gilmer, 1999). I asked Mary for her comments and what it brought forth in her as she read my paper. She spoke about the goals that she had stated in her written portfolio at the time (at the beginning, midway and at the end of the biochemistry course) and thought that had she had "maybe different goals, that could have helped me even more."

A year and a half after the biochemistry course ended, Mary reflected in an e-mail on what it was like for her reading the transcript of our earlier interview (that I had supplied to her) and the fictionalized story that I had written about the collaborations within the biochemistry course:

> I was touched to know that the personal things that I shared with you [in the interview] were printed in the transcript. This has enabled me to reflect what my life was like at that time. The first area that I noticed was my grammar. I immediately picked up on Magnolia [saying], "Uhh, huh." A close friend of mine, who also read the short story, confirmed that I speak in this manner. I also noticed some of my language during the interview. Surprisingly, I joined Toastmasters International during the fall of 1999. It is an organization that facilitates a workshop on public speaking. It has helped me to improve my speaking skills and grammar.

Mary's friends recognized Mary's voice in the story through the syntax of words that I chose, taken from Mary's interview with me.

Mary's group had three 15-minute group presentations on their group-generated Web sites. Mary was tentative in her speaking, especially in her group's first presentations in class. Mary knew that to become a teacher she needed to find her voice and become more comfortable in speaking. She took steps to address it. Mary commented further:

> The second area that I improved in was my fear of speaking in front of my peers. I had forgotten how shy I was when it came to presentations during college. The students in our class

[3] This story can be found on the Web where individuals can add comments through a highlighting function developed by David LeBow, using the HyLighting software: http://macramedia.net/hylights/experimenter/

were very competent in their science areas. I felt like a novice in our [biochemistry] content due to my low grades in my other science subjects. I also remember the anxiety I felt in front of my pre-service class. Now, I can speak anywhere to any one. I may stumble due to nervousness, but I have the confidence to open my mouth and know that there are clear, articulate, loud words that will come out.

I had a close relationship with Mary, and the interview with her opened me up to the concerns of students in the classroom. She has come to see me since graduating, and we stay in touch by e-mail.

Mary reflected on the use of technology and the Internet in our biochemistry class. At the start Mary was fearful of the technology, but she really grew considerably during the semester. She comments in an e-mail to me 18 months after the biochemistry class ended.

There are many experiences at Mabel Smith University that have shaped my craft of teaching. It has taught me to be compassionate, patient, and a visionary. The implementation of the Internet in our classroom gave us no boundaries. The most recent information on our subjects from epinephrine to glucagons was literally at our fingertips.

Mary has become the technology expert in her school in her country near Atlanta, Georgia. She has her students work in groups and make presentations. Even though I feel I required a lot of my students, she requires more of her students than I did. She feels that the biochemistry course had an indirect effect on her teaching career:

A standard project that I do with all of my classes (regardless of subject or grade level) is the Corporate Lab. The class becomes a business in a group networking setting. Each group contributes a part to the whole. The projects are: (a) a research paper on the topic that requires research in the library and the Internet (b) a PowerPoint presentation (c) a Web site and (d) a lab that the students come up with on their own. This project is challenging and very time consuming. However, it, is worth it because the benefits are numerous. Students gain training in computers, collaborative learning, research skills, inquiry skills, and workplace skills. There is only one product for each group so there are fewer papers to grade. However, there are daily assignments that are checked to keep the students on task. The outcome of projects has been different for each class. Some do great while others are overwhelmed by the amount of new information. I also try to integrate how other subjects, such as Math, History, English and a little Social Studies are explained to give correlations to Science. Overall, this Biochemistry course indirectly had an impact on my teaching career.

The second student whom I interviewed, Suzanne, gave me insights into how the developing fictionalized story that I wrote appeared to her as a student in our biochemistry class. Suzanne commented first on an early version of the story during the semester while I was still writing it, and again once I had finalized the story and put it on a Web site. For instance, about the student in the story who was "so busy," that she did not do her preparation for her group presentation, Suzanne said, "I think everybody has used this line. It's just not an excuse because school should be a priority on a student's schedule."

About collaboration, Suzanne said, "it does help our learning when there is someone to talk with," and "each of us made our contributions [to the Web sites], too." In the part of the fictionalized story in which story character, Magnolia, had said, "Constructing the Web sites is helping me *learn* the material instead of just memorizing and forgetting it," Suzanne responded, "That's how I felt." Suzanne did note within the collaborative group, "I did find that everyone had a pattern and a certain quality of work." When there were problems within a group, Suzanne commented, "I think it's critical to a group to get past problems and move on." When the storyline had the students considering telling the teacher about one group member not cooperating, Suzanne said, "This is hard to do because we feel that we're all adults and should be able to handle and resolve problems on our own." Furthermore, Suzanne stated, "Communication is critical. It allows the rest of the group to carry on and make adjustments, and it helps avoid unnecessary disputes."

In the part of the story when students are trying to decide what topic to select for their Web site, students are brining up their topics that they think might work, and Suzanne comments, "I remember feeling like this and seeing others enthusiastically talking about subjects they were interested in." She said that she regretted not putting enough time into it to see the common themes in what the group did. In the story I had the students meeting in the Technology Center, which did not exist at the time at Mabel Clark University. Suzanne commented: This would have been nice—a computer laboratory with Internet access where we could go anytime and talk freely." Instead the students sometimes met at coffee shops like Barnes & Nobles (I situated one part of the short story at such a bookstore).

These sorts of comments confirmed that I was pretty much on target as to what the features were within my classroom. Suzanne did have two comments in which I did not have it quite right, however, from her perspective. In the story I had one story character, Heather, start to collect the information for her Web site on Sunday afternoon and finish constructing the Web site later that evening. Suzanne commented, "This wasn't near enough time to do sufficient research, organize the information and our thoughts, and present it on the Web site." When the students in the story were trying to find a time to meet next, it took just a few comments back and forth, but Suzanne said, "It was never this easy to find a time that worked for everyone." I think what Suzanne was trying to tell me was that the organizing the research and finding time to work together was much more burdensome than I depicted in the storyline.

By using a special "hylighting" feature, Suzanne indicated how various portions of my story correlated with the classroom-learning environment. Therefore, I would say that interviewing these two students gave me insights into my classroom, and they both helped me, albeit in different ways, in writing and later editing the story about our classroom.

Although most of the students were planning careers in biology, chemistry, medicine or nutrition, 12% of the students in my class were future science teachers, and Mary was one of them. All students had to write their goals within electronic portfolios, at the beginning, midway and at the end of the course. I analyzed what the future teachers wrote of their goals in the class (Gilmer, 1999b). Through this analysis, I realized that it is important to understand the goals of one's students because you as the teacher can provide learning opportunities that help them meet their goals.

Collaborating with Science Educators in My Action Research Study

My co-major professors have been guiding me through the process of conducting action research in my classroom, via suggesting readings and other resources at various points in my slow evolution of becoming a science educator. I am proceeding on a slow and arduous pathway from being a "dyed in the wool" positivist to becoming a social constructivist. I remember being struck by reading what Yvonna Lincoln wrote: "As we absolve ourselves of the modernist fancy that texts can stand as memorials to the truth about the world, we let go of the last measure of certainty to which we might have clung" (Lincoln, p. 37, 1997). I struggled with this letting go of knowing some "truth" in the world.

I met with my major professors at various professional meetings for advice, new suggested readings, and "re-charging." With the graduate program at Curtin University of Technology being by distance education, I have had to gather much of the momentum on my own. This is hard because I already work a more than full-time job as a Professor of Chemistry and Biochemistry. However, the effort is well worth it because the growth from my action research is satisfying.

I experienced a tension between the styles of my two co-major professors. Tobin encouraged and provoked me to examine deeply the theories in science education and was more the taskmaster in my getting the chapters written, edited, and re-edited, while Taylor encouraged me to explore alternative ways of knowing but was less structured. It has been hard for me to reconcile these two approaches, but I have learned from each.

Conclusions

In summary, my transition from a scientist to a science educator has been less of a metamorphosis and more a slow evolution over twelve years since 1991 when I first met Ken Tobin. There have been some punctuated spurts of growth, but in general, it has been a slow evolutionary process to change my thinking.

I have found through this retrospective examination and reflection on this change in myself that collaboration has been a major thread in my life and in my teaching. Despite early, positive experiences in collaboration within science as a graduate student in biochemistry and as postdoctoral fellow in biophysical chemistry and immunochemistry, there was a general "rule" within the academic science community at my own university where I was in my tenure-earning period that I not collaborate (Figure 1) while I was an assistant professor. It was not until I was a tenured associate professor that I felt I could interact with other scientists (Figure 1) and science educators (Figure 2). The academic science education community welcomed me as a scientist into their community of learners. Therefore, collaboration with educators enabled me to move along the pathway of becoming a science educator.

I decided to check with a departmental colleague, William Cooper III, who arrived at my institution within a few years of my own arrival, to see how he perceived the environment for collaboration when he first came. He came approximately 23 years ago. I wondered did he feel like I did. I asked him:

> **I'm writing you to ask you how you felt as an incoming assistant professor about the environment for collaboration when you first came.**
> I got the very strong sense from my senior colleagues that collaborations with other **chemists** were not appropriate for an assistant professor. My situation was a little different, though, in that my interests were strongly interdisciplinary, and my desire was to collaborate with geologists, oceanographers, etc. Thus, I was not discouraged from those types of collaborations to a great extent. Indeed, I think the department was quite reasonable with regard to my collaborations **outside chemistry**. Of course, I did have to fight the perception that what I was doing was not mainline chemistry (which was true).
>
> **Also did the environment for collaboration change for you when you became as associate professor?**
> I certainly felt like it did. That was my perception, although it was not explicitly stated. Also, I have been collaborating extensively with Alan Marshall for five years, with only positive encouragement.
>
> **Do you think it's different now for the incoming assistant professors? If so, how? If so, do you think it's a good idea to have if different?**
> I do - I think there is a realization in the department now that interdisciplinary, multi-investigator research is the wave of the future, and if we are going to hire and keep the best young faculty, we need to encourage these collaborations. I think this is a VERY POSITIVE attitude.

I agree with Bill, an analytical geochemist, and feel that collaborative research is critical for all faculty members in our department. It was interesting to read that he felt that collaborative research was all right outside of chemistry but not inside our department when we were assistant professors. I am glad that he has found a good collaboration with one of our chemistry colleagues.

It is the activity diagrams (Figures 1 and 2) that allow me to see the coherences and contradictions in my autobiography as it relates to my teaching. The major contradiction in collaboration was through a "rule" that isolated me from collaborating as an assistant professor, especially in my first few years here, thereby influencing the communities with whom I could work. This influenced my flow, on the activity diagram, from subjects to objects (Figure 1).[4]

Once I started to interact with science educators, I felt a major coherence (Figure 2) existed within the "community of learners" atmosphere that I experienced as I learned about epistemology, theoretical perspectives, methodological approaches, and methods of analysis. Technology was a major contributor to my learning science education and collaborating with others (Tobin, 2002). I have learned different aspects of science education research from my two co-major professors, both of whom have contributed to the collaboration. Each one of them has influenced how I think about teaching and learning and how I teach my current classes.
I note the parallels between the collaboration that I experienced in my professional life as both a scientist and a science educator and the type of collaboration that I tried to promote in my biochemistry classroom. It was not until I was looking for themes in my teaching for my science education doctoral thesis that I realized the tension that exists between collaboration and autonomy. I tried to promote both collaboration and autonomy in my biochemistry classroom under study. Some students flourished in that environment, but some students could not live productively with that tension.

In my current STS classroom, since recognizing the tension between collaboration and autonomy, I highlight to my students that this tension exists and encourage each to learn to be both an autonomous learner and a collaborative learner. One needs to take responsibility for one's own learning but contribute to and benefit from the learning of others.

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[4] The policy in our department has changed some since I was an entering assistant professor, now 26 years ago. We just promoted and tenured another woman who not only did her own research but she actively collaborated with others. I think these interactions with others stimulated her research as well as the collaborative research.

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