# Science, Pedagogy, and Change: An Analysis of Science Faculty in a Higher Education Context, Responding to Change and Innovation

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## Introduction

Everett Rogers (2003) defines diffusion as a process by which an 1) innovation is 2) communicated through channels, 3) over time, 4) among the individuals of a social system. Much of Rogers' definition of the diffusion of innovation is focused around the idea of social structure and organizational culture: the culture of different organizations plays a very important role in the diffusion of innovations. This does not exempt the role that the attributes of an innovation has diffusion. However, the same innovation may diffuse differently through different cultures based on the properties of that culture.

Looking retrospectively at several instances of successful diffusion of similar innovations in a singular culture may provide an interesting window into the prospective and predictive values existing within a culture. A careful examination of how cultures and organizations reacted, in planned change terminology, may allow future innovators to take advantage of principles of diffusion that may lead to effective change.

One particular culture of interest is college science faculty. In the last several decades, much has been learned about effective teaching and learning strategies (Leonard, 1997). These findings have led to effective teaching practices. However, even in the presence of these reported data, many college science faculty are failing to adopt new teaching methodologies. Observation and analysis of several successful implementation programs may provide an intuitive and predictive method of analyzing college science faculty in the future.

## Presenting an Educational Gap

Starting in the early 1990s, several prominent national professional scientific advocacy groups (National Science Foundation (NSF), American Association for the Advancement of Science (AAAS), the National Research Council (NRC) and the National Academy of Science (NAS)) began to recognize some of the pedagogical failures in the teaching of college science. Until the early 1990s, many people viewed science, and therefore science teaching, as a broad set of measurable facts. *Benchmarks for Science Literacy* (AAAS, 1993) and *The National Science Education Standards* (NRC, 1995) were some of the first documents that recognized a fundamental need for science education to shift from the teaching of science as facts to the understanding of science as a set of skills and process (Leonard, 1997). This proposed shift in the understanding of science education also fit more in line with what researchers know about some of the principles of classroom learning. Older, objectivist pedagogy focused on the idea that scientific learning meant understanding science exactly the same way as the instructor (Leonard, 1997, Caprio, 1994). This is the antithesis of true science. While there are some overarching and important scientific principles worth knowing, most science education advocacy groups are pushing for a more constructivist and process oriented learning experience in college science instruction (Leonard, 1997, Grise and Kenney, 2003).

Overall efforts for the diffusion of this new pedagogical philosophy in college science education have failed (Leonard, 1997). Although there is much literature that supports the effectiveness of constructivist learning environments in science education (Leonard, 1997), the subsequent adoption has failed due in part to many barriers within

science faculty (Sunal et al., 2001). These barriers include lack of support, lack of resources and, perhaps more importantly, belief that the condition of introductory courses inhibits successful implementation of a new pedagogy (Sunal et al., 2001).

Many colleges and universities have growing enrollment in introductory college science courses (Lumsden, 1997, Grise and Kenney, 2003). For several reasons, including budget concerns, space, and faculty limitations, college administrations are using large courses to meet their administrative needs. These large sections, ranging from 75 – 1500 students, do not necessarily impede instruction (Grise and Kenney, 2003). These large sections, however, frequently provide impediments to constructivist teaching endeavors (Lumsden, 1997, Grise and Kenney, 2003, Weimer, 1994, Herreid, 2003). Some of the challenges of large class instruction are making learning active, personalizing course content, and helping students with diverse content backgrounds (Weimer, 1994). Based on studies of science faculty professional development and diffusion of innovation research (Sunal et al., 2001, Gamoran, 2003, Weidmann and Humphrey, 2002, Rogers, 2003, Ellsworth, 2000), researched and effective incremental change that is demonstrative of constructivist reforms may be most helpful bringing about the systematic reform goals of the NSF, AAAS, and the NAS. It will be important, then, to use small but effective constructivist solutions to the problems of college science.

Researchers disagree about the effectiveness of large group instruction (Grise and Kenney, 2003). However, most researchers acknowledge that standard lecture procedures are mainly ineffective. Standard lectures generally mean that one professor or lecturer tells the students exactly what they should know for the entire time allotted for the course. Current research has focused on two areas of course improvement. Instructor-

based initiatives (including inquiry-based, cooperative, interactive, and more personal (smaller groups) forms of lecture) put the power of change directly into the hands of the faculty. Student-based initiatives (e.g. web-based hybrid courses, supplemental instruction (SI), and attendance) are still created by faculty. However, the students bear the responsibility for improvement.

Educational research is constantly providing evidence for effective teaching practices. Current research in post-secondary science settings regarding inquiry, concept development, and pre/misconceptions has demonstrated that effective and innovative forms for teaching college science do exist (Sunal et al., 2001, Leonard, 1997). Although effective practices do exist to address the problems, change has been slow and the results are limited (Sunal et al., 2001). New methods of instruction are failing to disseminate among science faculty in general and as a result, students are leaving the sciences for other majors or electives (Sunal et al., 2001). Failure to adopt new methods of instruction could have devastating effects on the future of college science departments that fail to recruit new and enthusiastic students into their academic departments.

**Rationale for Surveying Successful Diffusion in Science Education Programs**

As a method for analyzing potential predictive variables in change within college science departments, a reflective survey of relevant literature was conducted. This was primarily a qualitative process employed in order to search for elements of change literature in several cases of successful change within college science instruction. Several recent articles were selected on the basis that they described a successful implementation

of new pedagogical strategies or that they included a professional development system that helped to cause an effective and lasting change in pedagogical philosophy. Three articles were selected and are described briefly below.

| Original Article Reference | Description of Article Content |
|---|---|
| 1. Sunal, D.W., Hodges, J., Sunal, C.S., Whitaker, K.W., Freeman, L.M., Edwards, L., Johnson, R.A., Odell, M.. (2001) "Teaching science in higher education: faculty development and barriers to change." *School Science and Mathematics*: 101(5), 246-257. | This original research sought to look for effective methods of conducting faculty development for college science faculty. Surveys were completed in order to determine what change barriers exist in college science faculty. |
| 2. Weidmann, W., Humphrey, M.B. (2002) "Building a network to empower teachers for school reform." School Science and Math, 102(2): 88 – 93. | This research describes a case study designed to study an effect professional development network that was set up in order to assist in transfer of knowledge gained from professional development into the effective use of pedagogical skills in the classroom. |
| 3. Gamoran, A. (2003) "What are they thinking?" Journal of Staff Development. 24(2): 56-60. | This case study followed six instructors in their efforts to implement new teaching and create meaningful learning in their students. This study focused on professional development networks and administrative support required for change. |

These three studies, although not described in change terminology, reveal several emerging and similar characteristics that, when combined, may help to create an important understanding of the culture of college science faculty. It is helpful, then, to describe the content of these articles in the change terminology created by diffusion scholars. In particular, three bodies of work may be very important points of analysis. 1) Everett Rogers (2003) describes in great depth the successful organization of diffusion networks. 2) Don Ely (Reiser and Dempsey, 2001) describes eight conditions that aid and support the diffusion and adoption of innovations. And 3) Zaltman and Duncan (Ellsworth, 2001) describe general barriers that prevent change. Understanding the current research articles based on change terminology may be helpful in describing general and predictive variables within college science faculty.

## Survey of Successful Diffusion of Pedagogical Methods within College Science Faculty

### *Ely's Conditions*

Comparison of change literature and three successful change implementations with college science faculties (see description of papers above, p 6) demonstrated many important relationships. The first analysis focused on Ely's conditions for change and how the various research efforts may have addressed these conditions (see figure 1 below).

| Ely's Conditions for Change | An Effective Professional Development Network Plan<br>Weidmann and Humphrey (2002) | Student - Centered Professional Development Scheme<br>Gamoran (2003) | Barriers To Change and Professional Development<br>Sunal et. al. (2001) |
|---|---|---|---|
| Dissatisfaction | Many people that participated in this study indicated that they were the only individual at their institution that taught a certain course and recognized a need for a change. | Teachers shared dissatisfaction. | Faculty will ONLY change if they feel that there is dissatisfaction with the current conditions. |
| Knowledge/ Skills | Several respondents acknowledged that there was a need for a change in pedagogy, but lacked the information or resources to do so. | There was minimal discussion of teachers needing to improve skills and knowledge. This is a potential shortfall for this examination of professional development. | Barrier: Cultural beliefs about pedagogy. Science faculties lack the skills and knowledge to implement new curriculum. |
| Resources | During the course of this study, the researcher noted that the academic departments may be ill-equipped to supply the resources for change. This project directly addressed the distribution of new resources. | This was a main point of the author. Departments need to do a much better job of providing resources for their staff. | Barrier: Faculties cite that they lack departmental and institutional resources for change. Also, professional development is lacking at many institutions. |
| Time | In order to allow time for more professional development, the researchers placed their networks into closer proximity, which Rogers (2003) notes are an important part of diffusion networks anyways. | Teachers all said that they needed more time for:<br>- Increasing networking<br>- Finding and nurturing leadership relationships<br>- Finding or creating resources | Barrier: Faculties cite that they lack the time they need to implement change.<br><br>Faculty need to plan finite and incremental changes at first in order to sway opinion leaders. |
| Rewards | No mention | No mention | Faculties cite ineffective practices in tenure and promotion and incentives for implementing change. |
| Participation | After the study located the people that would be most affected by this implementation, retention and further recruitment was very good. | The author pointed to the fact that departments need to provide a responsive and supportive environment for their participants. | Perhaps the most effective method of yielding participation is through the effective practice of personal action research among the opinion leaders within the group. |
| Commitment | Many people in this project were committed prior to entering the program. One aspect that this project did not address was the affect that this program had on institutions that did not feel a need to participate and why. | No mention | No mention |
| Leadership | This group provided leadership in the form of outside consultants that acted as strong opinion leaders for the participants. The consultants were heterophilous in their pedagogical action but homophilous in many other respects. | The author and many participants note the need for the administration to provide the leadership for the change processes. | Leadership:<br>- Needs to be supportive<br>- Needs to be present<br>- Needs to be personal and flexible |

*Figure 1 – This chart is a synthesis of how the three research papers may have addressed Ely's conditions for successful change. While the first two case studies address the presence of many factors, Sunal, et al. (2001) conducted a survey to demonstrate areas of potential need within the change process.*

Many of Ely's eight conditions for change were described, albeit without mention of Ely. In regards to all eight conditions, the first four seem to be the most commonly critical in setting up the culture for change. In fact the condition of dissatisfaction may be the most elementary requirement for change. This was especially apparent in Sunal et al. (2001). Their survey demonstrated that above all other areas, faculty would only change if they felt the need for change. This alludes to the fact that change agents must present a clear and focused demonstration of need and that need has to be tied with faculty discontent.

Sunal et al. (2001) also demonstrated that even if faculty members recognize a need for change, they lack the skills or knowledge to implement successful change in their pedagogical methods. This was echoed in Weidmann and Humphrey (2002). For this reason, successful professional development plans have to focus on transfer of pedagogy into practice.

***Zaltman and Duncan – Barriers***

Zaltman and Duncan (Ellsworth, 2001) describe four main categories of barriers to successful adoption of change (see figure 2 below). Their barrier research sorts by the following categories: cultural barriers, social barriers, organizational barriers, and psychological barriers. Analysis of these barriers as they were commonly expressed in Sunal et al. (2001) should elucidate which potential barriers will provide the most challenging and in need of redress in professional development schemes.

| Major Resistance Categories | Cultural Barriers | Social Barriers | Organizational Barriers | Psychological Barriers |
|---|---|---|---|---|
| Sub-Categories of Resistance | - Values and Beliefs<br>- Cultural Ethnocentrism<br>- Saving Face<br>- Incompatibility of a cultural trait with change | - Group Solidarity<br>- Rejection of Outsiders<br>- Conformity to Norms<br>- Conflict<br>- Group Introspection | - Threat to Power and Influence<br>- Organizational Structure<br>- Behavior of Top-Level Management<br>- Climate for Change Technology | - Perception<br>- Homeostasis<br>- Conformity and Commitment<br>- Personality |

*Figure 2 – Zaltman and Duncan's barriers to change – Main barriers are subdivided into sub-categories of potential threats.*

| Overall Barriers | Barriers to Change (From Zaltman and Duncan) |
|---|---|
| Culture (belief that telling is teaching) | *Culture*: Tradition, Cultural Ethnocentrism<br>*Social*: conformity to norm<br>*Psychological*: homeostasis, conformity |
| Lack of Professional Development | *Organizational*: technology, climate for change |
| Context and Organization: Lack of reward and incentives | *Organizational*: organizational structure, climate for change |
| Perceived realities block large change | *Psychological*: perception |
| Instructors beliefs limit large change | *Cultural*: values and beliefs<br>*Psychological*: perception |
| Major Barriers | |
| Resources | *Psychological*: perception<br>*Organizational*: organizational structure, climate for change, technology |
| Time | *Psychological*: perception |
| Turf: Spatial or Content | *Psychological*: perception<br>*Social*: conflict |
| Minor Barriers | |
| Students diverse backgrounds | *Psychological*: perception |
| Personal resistance to change | *Psychological*: perception, homeostasis, conformity & commitment, personality<br>*Social*: conformity to norms<br>*Cultural*: cultural ethnocentrism, values & beliefs, incompatibility |
| Untrained or unqualified opinion leaders | *Organizational*: organizational structure, climate for change<br>*Psychological*: perception<br>*Cultural*: cultural ethnocentrism<br>*Social*: solidarity, rejection of outsiders |
| Change requires committee approval | *Organizational*: All factors |
| Lack of personal training | *Psychological*: perception |
| Lack of leadership | *Organizational*: All factors |
| Institutional barriers | *Organizational*: All factors |
| Lack of curricular material | |

*Figure 3 – Comparison of Sunal et al. (2001) barriers to college science faculty development and Zaltman and Duncan's (Ellsworth, 2001) general barriers to change. In the left hand column, items highlighted in yellow indicate barriers that faculty members can control themselves. In the right hand column, the italicized words represent overall barrier categories.*

This barriers analysis demonstrates that many of the barriers listed by faculty members as overall or major barriers of change fall under a variety of change barriers. Overall barriers were the main items that almost all faculty members surveyed listed as obstacles to personal change. Although these barriers vary according to Zaltman and Duncan, they point to the fact that there are both cultural (the beliefs about teaching) and organizational (climate and structure for change) that hinder adoption of new pedagogical philosophies. This might point to potential areas that change agents should focus on during the development of a need for change. By looking at the organization of the faculty system and their current beliefs about teaching, change agents may be very persuasive in showing the need for a fundamental re-thinking of individual philosophies of instruction.

Another interesting point is shown in the area of "Major Barriers." Major barriers are defined as those barriers that were mentioned by many at least 60% of respondents. Each one of these barriers (time, resources, and turf) sorts into Zaltman and Duncan's category of psychological perception barriers. The fact that these barriers can be described as a perceptual paradigm is important to the creators of professional development and change agents. Sunal et al. describe these parameters as out of the control of faculty members. Professional developers can focus on re-framing the control of these variables and show the ability to plan an implement based on the values that are important to individual faculty members.

### *Rogers' Diffusion Networks*

Rogers (2003) describes the importance of networks to the diffusion of innovations. Rogers describes that individuals within a network are more likely to adopt

an innovation if more people in the network adopt that innovation. Adoption can be described with an S-shaped curve (see figure 4 below). Critical mass is the point at which the rate of adoption is occurring at a pace which will become self-sustaining. Therefore, the quicker critical mass can occur in a network, the more rapid the adoption process will occur.

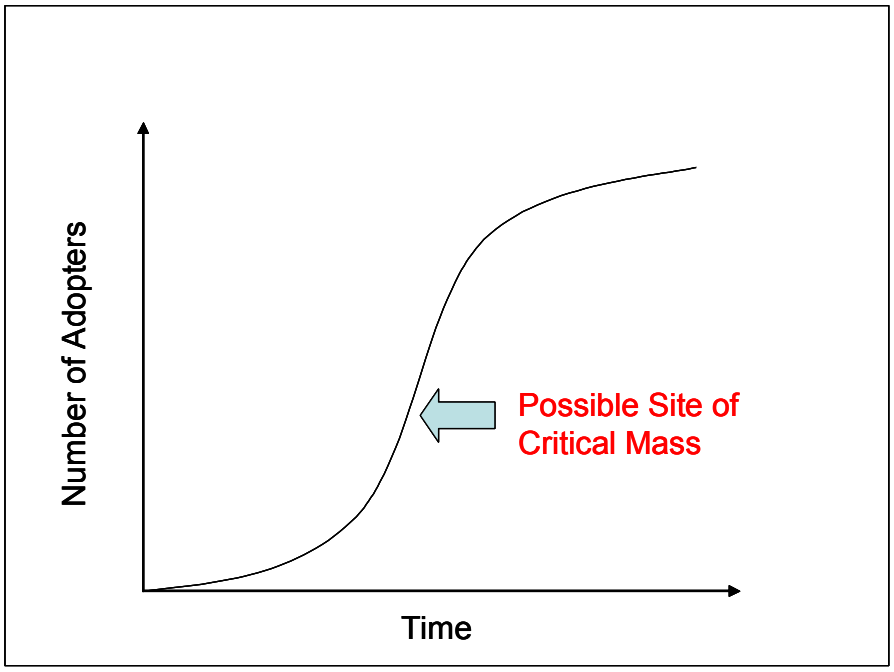


*Figure 4 – Diffusion of an innovation over time within a network. The arrow points to a site where critical mass should occur.*

Rogers describes opinion leaders as being keys within diffusion networks for promoting adoption among other users. Opinion leaders tend to lead other members of a network into adoption of change. Opinion leaders within a diffusion network provide homophiliy, or are more similar to the rest of the network. Change agents are often heterophilious, or different from the individuals in the network. Rogers alludes to the necessity of this mix of homophiliy and heterophiliy in order for diffusion to be successful, although, too much homophily in a change agent could be could be a barrier for diffusion by acting as an invisible impediment to rapid flow of innovation. For

example, if there are no members of the science faculty that are instructional specialists, new research will probably not be evident within that department.

Weidman and Humphrey (2002) discuss the development of professional development networks in order to more effectively foster change in pedagogical thinking. They describe a critical ingredient in their professional development networks being external "consultants." Weidman and Humphrey describe consultants in a manner that is consistent with two roles in change literature. In a weak sense of the term, the consultants act as change agents in that they enter a new system and provide a heterophilious stance based on teaching practice. This fits into Rogers' (2003) definition of a change agent as someone that operates interventions in order to bring about behavioral change. In this case, heterophiliy acts to the benefit of the consultant because they represent the new view of teaching. These consultants also act as potential opinion leaders within the professional development networks. The consultants (based on the Weidman and Humphrey work) are selected because of their high standing in their field of teaching. This makes the consultants homophilous in position, making this an effective use of practicing professionals in a dual role as change agent and opinion leader. In comparing Weidman and Humphrey's consultants with Rogers' opinion leaders, several similarities, mainly prestige, are in common (see figure 5 below).

| Characteristics of Professional Development Networks – Weidmann and Humphrey (2002) | Characteristics of Diffusion Networks - Rogers (2003) |
|---|---|
| Professional development consultants need to be practicing professionals:<br>- Heterophiliy in practice<br>- Homophiliy in position | Too much homophiliy can be a barrier to diffusion |
| Key characteristics of good consultants:<br>- Faculty practicing innovative pedagogy<br>- Faculty with departmental influence<br>- Faculty from prestigious universities | Characteristics of a good opinion leader:<br>- Greater external communication<br>- Ease of accessibility<br>- Higher socioeconomic standing<br>- High degree of innovativeness |

*Figure 5 – This is an illustration, side by side, of the characteristics of effective "consultants" (Weidman and Huphrey, 2002) and characteristics of effective diffusion networks (Rogers, 2003). There are important similarities between the "consultants" and Rogers' opinion leaders.*

Weidman and Humphrey offer a practical guide to establishing good professional development networks. In order to examine why these guidelines might have been effective, they have been placed next to Rogers' strategies for achieving critical mass in diffusion networks (see figure 6 below). The colored arrows indicate matches between Weidman and Humphrey and Rogers. This is an important consideration for professional development and, perhaps, this comparison helps to validate the efficacy of the professional development networks described by Weidman and Humphrey.

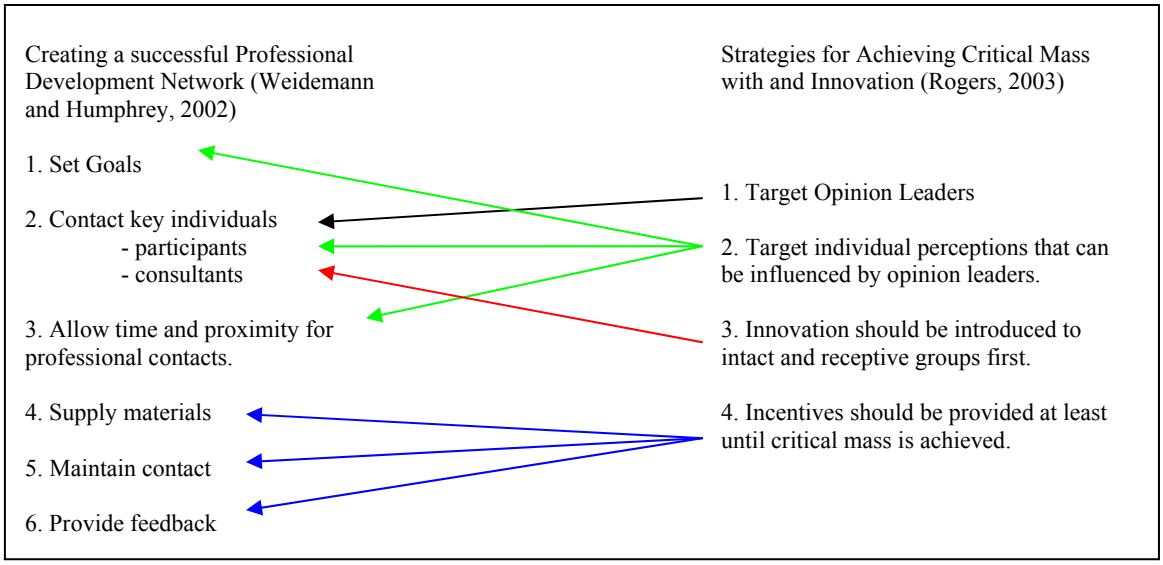


*Figure 6 – This picture illustrates a potential professional development plan that was particularly effective in both physical retention of participants and participants' retention of content. The lines represent possible correlations between components of the Professional Development Network and Roger's Strategies for improving Diffusion Networks.*

### *Conditions for Successful Course Change*

Sunal et al. (2001) provides a synthesis of nine conditions that may be essential for successful college science course change. Again, for comparison purpose, these conditions were qualitatively analyzed based on the change literature, except these conditions were compared to Rogers' diffusion networks, Ely's conditions for change, and Zaltman and Duncan's barriers to change (see figure 7 below).

| Conditions for Successful Course Change (Sunal et. al., 2001) | Corresponding Change Terminology |
|---|---|
| 1. Increased interaction of faculty members between disciplines relates to change. | Rogers - Diffusion Networks<br>Zaltman & Duncan – Barriers: Cultural, Social, Organizational |
| 2. The greater the change required the more administrative support is necessary. | Ely's Conditions → Leadership<br>Ely's Conditions → Resources<br>Ely's Conditions → Time<br>Ely's Conditions → Participation<br>Zaltman & Duncan – Barriers: Organizational |
| 3. Administrator presence in some part of the change process is necessary. | Ely's Conditions → Leadership<br>Ely's Conditions → Resources<br>Ely's Conditions → Time<br>Ely's Conditions → Participation<br>Zaltman & Duncan – Barriers: Organizational |
| 4. Change begins with setting goals. | Ely's Conditions → Leadership |
| 5. Connections with others having similar goals are important. | Rogers - Diffusion Networks<br>Rogers - Homophiliy<br>Zaltman & Duncan – Barriers: Social, Cultural |
| 6. Collaborative work starts with building effective interpersonal skills and trust to facilitate change. | Rogers - Diffusion Networks<br>Ely's Conditions → Skill/Knowledge<br>Ely's Conditions → Leadership<br>Zaltman & Duncan – Barriers: Social, Cultural |
| 7. Planning incremental change is a successful staff development process. | Ely's Conditions → Leadership |
| 8. Action Research is an important process for providing faculty with a picture if the need for change. | Ely's Conditions → Dissatisfaction |
| 9. Joining a network of faculty within or outside of institution that disseminates results of change facilitates adoption. | Rogers - Diffusion Networks<br>Ely's Conditions → Dissatisfation<br>Zaltman & Duncan – Barriers: Social, Cultural |

*Figure 7 – Sunal et al. (2001) Conditions for successful course change in college science education compared to Rogers' diffusion networks, Ely's conditions for change, and Zaltman and Duncan's barriers to change.*

In the analysis of the conditions for successful course change in college science education (Sunal et al., 2001), several recurring themes are presented. First, and potentially foremost, that the development of strong professional networks may foster influential networks is very important. Of the nine conditions, four directly mention the

use of networks in order to share information, particularly on information about need for change and potentially effective pedagogical interventions. This coincides with Zaltman and Duncan's research on barriers. In order to establish and manage effective faculty networks, much attention will need to be paid to the social and cultural barriers that college science faculty present (see figure 3 above). In particular, college science faculty has a cultural belief that teaching is telling (Sunal et al., 2001). This view is contradictory to the currently known views about how the brain learns (Leonard, 1997, Ormrod 1999, Kandall, et al. 1997, Brooks and Brooks, 1999). However, college science faculty also has a societal belief that rejects the views of outsiders (Sunal et al., 2001, Ellsworth, 2001). Based on this information, the best professional development networks would include individuals with a fair amount of homophily, especially if the overall goal of the professional development is to cause the diffusion of an innovation that is inconsistent with the perceptions of college science instructors.

Looking at Ely's conditions for successful change, similar important conditions resurface (figure 1 above). One key element is dissatisfaction. More important, based on these suggested conditions, are the conditions about resources, time, and participation. These conditions fall into Zaltman and Duncan's barrier work. Dissatisfaction, time, resources, and participation can all be influenced by targeting of perceptions of faculty members. Based on the preceding discussion of professional development networks, the most successful way of targeting these individual's perceptions could be through homophilous opinion leaders.

Finally, strong leadership seems to be a fairly important factor in successful change. This is a hint, again, to effective leadership (potentially opinion leadership)

within professional development networks. Although Sunal et al. allude to influence from administration (figure 7 above), the barriers described about the need for homophily in practice must be respected in order to provide the leadership necessary for successful change and adoption.

## Retrospective to Prospective: Using Past Research to Prescribe Effective Suggestions for Change

Based on a review of three successful programs that had a similar goal of influencing a change in pedagogical thinking in college science instruction, several overall suggestions can be made in order to ensure the efficacy of either professional development or change agents. Change agents, as mentioned previously, are agents that operate interventions in order to change behaviors and increase the rate of innovation decisions (innovation decisions → the process that starts with knowledge of an innovation and leads to individuals or groups past adoption and into institutionalization (Rogers, 2003).

1. Above all and at every level and stage, anyone interested in meaningful change in college science education has to be able to present the need for change in order for the change to be adopted. Due to cultural and social barriers (figure 2 and 3 above), this message of need has to be presented by individuals with some level of homophily with the faculty. Opinion leaders should be identified and selected early.
2. Development of a professional development network (see Weidman and Humphrey, 2002 and figure 6) that includes a group of faculty members that are

homophilious in position but heterophilious in practice will help in the influence of adoption.

3. Leadership is important in two main aspects, providing support and helping to influence perceptions within faculty members. To some extent, peoples' views of time, resources, and their own behavior and knowledge can be redefined and restructured in order to be used as positive aspects.
4. Professional development has to reinforce transferal into practice, for this reason, it important to view professional development as a continuous process and not a series of one time opportunities.

There are many possible next steps from this point. Much of the research on diffusion of innovation and adoption is focused on retrospective studies of events or implementations that have already occurred. It would be a logical next step to turn this research into prospective predictions about the potential for adoptions in different populations. In this case, it would be interesting to spread this particular study out over more pieces of literature. It might also help to survey two different populations of college science faculty members, adopters and non-adopters, in order to see if these same issues were the issues that were present. Finally, it would be crucial to see if it would be possible to develop an instrument that would measure the organizational climate before there is an attempt to introduce change into a population.

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