EDITORIAL

In this editorial I would like to briefly address some issues related to scientific thinking in educational practice. One could claim that in this time of education reform and focus on accountability, we are being asked to demonstrate that our expertise and skills have been integrated with science—that our instructional models, methods, and materials should be able to show that a specific treatment will be effective. Say for example, if the curricula/lessons are not based in the science of pedagogy, it is likely that they will fail.

Education is informed by formal scientific research through the use of research-based knowledge. Scientific thinking in practice is what characterizes reflective teachers—those who inquire into their own practice and who examine their own classrooms to find out what works best for them and their students. Reflective teachers are effective consumers of the literature that results from the conduct of formal scientific research in education; they can think scientifically in their ongoing reflection about their classroom practice. Being able to access and apply mechanisms that evaluate claims about teaching methods and to recognize scientific research and its findings are especially important skills for reflective teachers to possess. It is well known that there is no such thing as best practice in education, that there are no ways to verify what works best, that we should base our practice on intuition, or that the latest trend must be the best way to teach, or address local school reform. Such view in the field of education is often called anything goes. It is actually a dangerous view that might support the environment where untested and not supported by an established research basenot-supported-by-an-established-research-base educational remedies are are accepted.

Scientific thinking in practice occurs when we engage in action research, which is research into one's own practice that has, as its main goal, the improvement of that practice. One factor that has impeded teachers from being active and effective consumers of educational science is a lack of orientation and training in how to understand the scientific process and how that process results in the cumulative growth of knowledge that leads to validated educational practice. Educators have only recently attempted to resolve educational disputes scientifically, and teachers have not yet been provided with the skills and support to be able to evaluate disputes on their own. The educational community of practitioners needs tools for evaluating the credibility of these many and varied sources of information; the ability to recognize research-based conclusions is especially important. Acquiring those tools means understanding of scientific values and learning methods for making inferences from the research evidence that arises through the scientific process. These values and methods were summarized by Shavelson and Towne (2002) at the panel of the National Academy of Sciences convened on scientific inquiry in education. In their discussion of the evolution of the American Educational Research Association (AERA) conference and the importance of separating research evidence from opinion when making decisions about instructional practice, Levin and O'Donnell (2000) highlighted the importance of enabling teachers to become independent evaluators of research evidence. Many advances in science came through use-inspired research, which draw upon observations in applied settings. The current problem is how to sort through the mass of misguided and uninformed advice to find genuine knowledge. Our problem is not information; we have an overabundance of information. What we need are quality control mechanisms rather than blind consumption of the latest fads in prescriptive medicine that later turn out to be harmful to the human system. The scientific criteria for evaluating knowledge claims are not complicated and could easily be used by teachers who want to become more efficient and autonomous in their work. These criteria include critical examination the publication of findings in refereed journals, effective duplication of the results by other investigators, and a consensus within a particular research community on whether there is a critical mass of studies that point toward a particular conclusion.

Regina M. Panasuk
2007 Annual Spring Colloquium Journal
The Graduate School of Education, University of Massachusetts Lowell

GUIDELINES FOR SUBMISSION

The papers submitted for the Journal must discuss psychological and pedagogical issues and trends related to mathematics and science education.

WHEN SUBMITTING A PAPER, PLEASE USE THE FOLLOWING GUIDELINES:

1. Submit an electronic version of the paper and one hard copy, an abstract, approximately 150 words, and a biographical sketch, about 30 words. All pictures and diagrams must be submitted in a separate document.

2. Use double spacing with one-inch margins.

3. For references, tables, and figures, follow the style described in the Publication Manual of the American Psychological Association (APA), Fifth Edition.

4. Paper length should not exceed 30 pages, including pictures, tables, figures, and list of references.

5. Paper must be received by November 15.

6. Authors will be notified about the status of their papers by January 15.

7. The Colloquium is scheduled in April.

SUGGESTIONS TO THE AUTHORS:

When preparing a research paper include:

a) a rationale and an identification of the research question(s)

b) a conceptual framework or brief statement of relationship to the literature

c) an identification of research methodology

d) a summary of the analytical technique(s)

e) a summary of preliminary findings

SUBMIT PAPERS AND CORRESPONDENCE TO:

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2006-2007 Academic Year
Mathematics and Science Education Program

DISSERTATION DEFENSE STAGE
Linda McAlpine
An Investigation of the Developmental Mathematics Community College Students’ Attitudes Regarding Computer-Assisted Learning
Peggy LaBrosse
An Investigation of the High School Chemistry Students’ Understanding of Academic Language and Achievement
Danielle Godwin
Exploring the Relationship Between High School Teachers’ Mathematics History Knowledge and Images of Mathematics

DISSERTATION PROPOSAL STAGE
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QUALIFYING PAPER STAGE
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Valerie Finnerty
Chester Orban
Noreen Flanagan
Matthew Beynavenard
Deirdre Donovan
Mike Wadness
Sachiko Tosa
Instructional Efficacy Beliefs of New, Career-Change Mathematics Teachers: The Important Role of College Supervision

Charmaine P. Hickey, Ed.D.
University of Massachusetts Lowell

ABSTRACT

The question of how to retain new, highly qualified teachers in schools and in the teaching profession is one current crisis in education with an elusive solution. Using social cognitive theory (Bandura, 1997) as a theoretical base, this study examines what may be at the root of teacher attrition: efficacy beliefs. With the help of NVivo® software, a qualitative approach is taken to explore the teacher efficacy beliefs of three first-year, career-change mathematics teachers in an urban setting, as they were supervised by a college professor for the first time. The study reveals an expanded role for the college supervisor and how the teachers attend to the sources of efficacy being offered to them. Teacher efficacy beliefs and their implications are important for graduate schools of education, career-change individuals wishing to become mathematics teachers, and urban schools and school districts. The study lends support to the statement that teacher efficacy beliefs are “a little idea with big impact.”

RATIONALE AND IDENTIFICATION OF THE RESEARCH QUESTION

Efficacy is a little idea with big impact. This paraphrased statement made by teacher efficacy belief researchers (Tschannen-Moran & Woolfolk Hoy, 2002) provides a stepping stone to unfolding and understanding the notion of teachers’ efficacy beliefs. This study poses the question, “What is the role of college supervision as a factor contributing to the construction of teacher efficacy beliefs of new career-change mathematics teachers in an urban setting?” Qualitative research is used to provide an image of the teacher efficacy beliefs of three new career-change mathematics teachers in an urban setting. In this study, the background compo-

<table>
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<th>Name</th>
<th>Highest Degree</th>
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<th>School Level Work Prior to Study</th>
<th>Subject Currently Teaching</th>
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<td>Tiffany L. Jones</td>
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<td>Math-related</td>
<td>Middle School</td>
<td>Mathematics</td>
</tr>
</tbody>
</table>

Table 1

Brief overview of characteristics of study participants.

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other two participants were employed in separate high-need urban middle schools. Each participant had earned at least an undergraduate degree in a mathematics-related field, but not in education. All of the participants were older than traditional teacher education students by virtue of their past educational and work experience. Additional demographic information was requested during the study. Table 1 illustrates basic information about the participants who are each identified by pseudonyms: Chantal, Justin and Tiffany.

Participants are located in the foreground of the study with the contexts of environment, theory, and inquiry constituting the background against which interpretations are made. The researcher's visual representation of the study overview is presented in Figure 1.

**STATEMENT OF THE RELATIONSHIP TO THE LITERATURE**

**ENVIRONMENT**

One aspect of this study provides both a focus on and perspectives of a purposeful sample of alternative route certification career-change mathematics teachers in an urban Massachusetts setting. Alternative route certification, for this study, is defined as any program that offers a means to full-time teaching without the completion of education coursework and/or a student teaching practicum. In the program used as a context for this study, graduate education coursework is required, but no student teaching practice is completed. Instead, enrolled students engage in an internship assuming full teaching responsibility. Alternatively-certified career-change individuals, such as those in this study, account for 45% of all new teachers in Massachusetts (Harvard Graduate School of Education, 2003). Massachusetts is host for one nationally-funded program that joins a multitude of federal, state, and district programs offering routes to alternative teacher certification for career-change individuals. This Massachusetts-based graduate-level alternative route certification program for those aiming to become mathematics or science teachers contributes to the environment for this study. One Massachusetts urban district employs three mathematics teachers who are in the aforementioned program and who experienced college supervision for the first time in

---

**Figure 1.** Overview of the structure of this study. Foreground focus on participants and their efficacy beliefs; background components of theory, inquiry and environment influence the study.
Spring 2005. In the context of the alternative route certification program in this study, college supervision is taken to mean a formative and summative evaluation of the teacher provided by a college-assigned teacher/supervisor. The urban district provides further nesting for this study. For the purpose of this study, an urban district or school is one that meets the federal definition of a high-need school.

**Theory**

Another lens that provides focus and perspective for this study is that of theory. Social cognitive theory envelopes human agency and efficacy. Social cognitive theory (SCT) is one theory of behavioral change concerned with human agency, or the ways that people exercise some level of control over their lives (Bandura, 1997). In SCT, human “agency refers to acts done intentionally” (Bandura, 1997, p. 3). These intentional acts operate within a framework that Bandura (1997) termed triadic reciprocal causation. In social cognitive theory, triadic reciprocal causation is the concept that personal, behavioral, and environmental factors all operate as interacting determinants that influence (as opposed to cause) one another bi-directionally (Bandura, 1986, 1997; Tschannen-Moran, Hoy, & Woolfolk Hoy, 1998). The interaction of the three factors in triadic reciprocal causation works on human agency which impacts efficacy. On a personal level, “perceived self-efficacy refers to beliefs in one’s capabilities to organize and execute the courses of action required to produce given attainments” (Bandura, 1997, p. 3). Efficacy beliefs “constitute the key factor of human agency” (Bandura, 1997, p. 3). The nested nature of SCT, agency and efficacy illuminates one reason for the claim that efficacy is a little idea with big impact (Tschannen-Moran & Woolfolk Hoy, 2002).

**Efficacy**

This study examined what may be at the theoretical root of teacher attrition: efficacy beliefs. “Perceived self-efficacy refers to beliefs in one’s capabilities to organize and execute the courses of action required to produce given attainments” (Bandura, 1997, p. 3). Self-efficacy beliefs are concerned with the orchestration of skills (Bandura, 1997; Valiante, 2004).

Bandura listed four sources of efficacy beliefs: mastery experiences, physiological and emotional states, vicarious experiences, and social persuasion (Bandura, 1994, 1997; Tschannen-Moran, Woolfolk Hoy, and Hoy, 1998). Bandura explained that the four sources of efficacy information are then processed cognitively through reflective thought to yield their impact on efficacy (Bandura, 1997). Reflective thought about the four sources of efficacy determines what the individual attends to and how much weight is given to each source in the construction of efficacy beliefs (Bandura, 1997). Each source of efficacy information is considered in turn.

Mastery experiences give the opportunity for one to experience success in a given situation. Successful experiences generally raise efficacy beliefs which contribute to the expectation that performance will be proficient in the future (Ebmeier, 2003). Mastery experiences are the most influential of the four sources of efficacy information because they provide what Bandura (1997) calls the most “authentic evidence” (p. 80) of whether one can attain a given goal.

Physiological and emotional states are the extent to which performances can be attributed to internal or controllable causes – not luck. The level of anxiety or excitement also plays an important role (Ebmeier, 2003). Bandura (1997) indicates that countering the negative effects of physiological and emotional states on efficacy is to enhance physical status, reduce stress levels and negative emotional tendencies, and correct misinterpretations of bodily states such as aches and pains (Bandura, 1997).

Vicarious experiences are those that occur when one has learned by observing the performances or skills of others and can identify with the performer (Ebmeier, 2003). Bandura also refers to vicarious experiences as modeling, which can be either verbal or behavioral (Bandura, 1997). Vicarious experiences allow people to appraise their capabilities in relation to the attainments of others through social comparison. One’s resulting self-efficacy beliefs will vary greatly depending upon the talents of those chosen for social comparison (Bandura, 1997).

Verbal persuasion is when one has received specific performance feedback from a supervisor or colleague. Receiving encouragement to the extent that it boosts risk taking performances increases efficacy (Ebmeier, 2003). Bandura calls this source of efficacy information social persuasion. Bandura indicates that verbal persuasion serves as a means of strengthening people’s beliefs that they possess the capabilities to achieve what they seek (Bandura, 1997). He further states that verbal persuasion has the greatest effect on those who already have some reason to believe that they can succeed through their actions (Bandura, 1997). In all cases, it is more difficult to instill enduringly high efficacy beliefs by verbal persuasion alone than it is to undermine such beliefs (Bandura, 1997).
TEACHER EFFICACY BELIEFS

The concept of efficacy extends to the teaching profession. Teacher efficacy beliefs are “a little idea with big impact” (Tschannen-Moran & Woolfolk Hoy, 2002, p. 7). A teacher’s self-efficacy beliefs are defined by Tschannen-Moran and Hoy as “a teacher’s judgment of his or her capabilities to bring about desired outcomes of student engagement and learning, even among those students who may be difficult or unmotivated” (Tschannen-Moran & Hoy, 2001, p. 783).

In this section the importance and derivation of teacher efficacy beliefs are discussed. One particular model of teacher efficacy beliefs, used as the framework for this study, is highlighted.

One conceptual strand of theory and research grew out of the work of Bandura (1997). This strand identified teacher efficacy as a type of self-efficacy—a cognitive process in which people construct beliefs about their capacity to perform at a given level of attainment. Bandura (1997) suggested that teacher efficacy reflects a teacher’s belief that he or she is personally capable of influencing student learning (Joffres & Haughey, 2001). As with self-efficacy, these beliefs influence how much effort teachers put forth, how long they will persist in the face of obstacles, their resilience in dealing with failures, and how much stress or depression they experience in coping with demanding situations (Bandura, 1997). Bandura (1997) points out that teacher efficacy is not necessarily uniform across the many different types of tasks teachers are asked to perform, or across different subject matter. In response to the context and situation-specific nature of teachers’ efficacy, Bandura (2001) constructed a 30-item instrument with seven subscales: efficacy to influence decision-making, efficacy to influence school resources, instructional efficacy, disciplinary efficacy, efficacy to enlist parental involvement, efficacy to enlist community involvement, and efficacy to create a positive school climate (Tschannen-Moran et al., 1998). This instrument was used in this study to survey the participants.

Little evidence exists about how efficacy beliefs change or solidify across stages of a career (Tschannen-Moran et al., 1998). However, studies that have looked at the development of efficacy beliefs among novices indicate that efficacy beliefs of first-year teachers are related to stress and commitment to teaching as well as satisfaction with support and preparation. Novice teachers completing their first year of teaching who had a high sense of teacher efficacy found greater satisfaction in teaching, had a more positive reaction to teaching, and experienced less stress. Additionally, efficacious novices indicated greater optimism that they would remain in the field of teaching (Burley, Hall, Velleme, & Brockmeier as cited in Tschannen-Moran et al.; Hall, Burley, Velleme, & Brockmeier as cited in Tschannen-Moran et al.).

In fact, teacher efficacy’s impact on commitment is far from clear or consistent. Whereas Louis (1998) and Coladucci (1992) found that teacher efficacy was directly related to commitment, Fresko, Kifir, and Nasser (1997) found that the same variable was not directly related to commitment but was directly related to job satisfaction. Such discrepancies may partly result from the different conceptualizations of efficacy.

TEACHER EFFICACY AND JOB SATISFACTION

Studies show that working with students is the primary motivating factor for teachers who remain in the profession and have a high level of job satisfaction (Brunetti, 2001; Madfes, 1990). Successfully assisting students to achieve at high levels has been linked to increases in teacher efficacy (Bandura, 1997). Although student achievement is not the focus of this study, the relationship between teachers’ self-efficacy beliefs and student achievement must be acknowledged. In turn, teachers’ high efficacy beliefs may be one of the contributing factors in teacher retention (Bandura, 1997; Coladucci, 1992).

INQUIRY

While extending the literature on teacher efficacy beliefs, this study uses a qualitative research approach to inquiry that is generally uncommon to teacher efficacy belief research. A combination of surveys (Bandura, 2001), audio-recording of supervisory meetings, teacher reflection logs, and semi-structured interviews provide a perspective of teacher efficacy beliefs from the teachers’ viewpoint. The qualitative software tool NVivo® is used continuously throughout this study, not only for data collection and analysis, but for an ongoing search for relationships, patterns, thoughts, and visual representations of emerging NVivo® models that help the researcher to think about how the process of efficacy construction works in this study. Additionally, NVivo® serves as a place to collect and integrate the researcher’s thoughts, questions, and methodological decisions throughout the project.

Inquiry using this methodology is an important part of the study background. Thinking about inquiry is inextricably intertwined with the researchers’ relationship with the participants; with anticipating how the data will look and how it will be accepted into the proj-
ect — something the researcher terms The NVivo® Shell (Hickey, 2005), and with the meanings that are worked out of, or emerge from the data. Analytical techniques are further described in the following section.

**A SUMMARY OF THE ANALYTICAL TECHNIQUES**

**DATA MANAGEMENT AND ANALYSIS WITH NVivo®**

Data management and analysis was on-going during this study. NVivo®, a qualitative software tool, was used to aid in this on-going task. The use of NVivo® software is integrated throughout this study because the researcher’s choice to use this software and the methods for using it are inextricably intertwined with the depth of this study and the manner in which it was conducted.

**The NVivo® Shell**

Thinking about what data would be collected during this study, how it would be structured and managed, and how it ought to be analyzed led to creating the notion of The NVivo® Shell. Even prior to data collection at the beginning of any research project, the researcher should examine potential structure, data management, and analysis strategies.

The idea of the NVivo® Shell is a useful representation of how to look at a qualitative research project using the software. Similar to a sea shell, the project can be viewed as unique to each situation; fragile until the data are loaded into the project; still changeable even after the initial shell has been established; useful in managing data and allowing data to be questioned; taking on different shapes or colors; and willing to accommodate many different kinds of data. One can imagine a parallel between a shell that accommodates data and a shell that accommodates any life form that can make the shell its home. The shell gives structure and form to the project, even prior to accepting its “residents”!

Having this tool and including the notion of The NVivo® Shell in this research is important for at least two reasons. First it gives the researcher the option of using the full potential of NVivo® to focus on asking questions of the data through NVivo® visual modeling, searches, and scopes, and assays, as opposed to becoming mired in the data management. Second, it contributes to the trustworthiness of the research as one reads the project (Davidson, 2005).

**DATA MANAGEMENT**

Data collection for this study yielded four types of data: survey results, transcripts of audio-recorded college supervisory meetings, interview transcripts, and text of reflection logs. Complementary to these primary data sources was a pre-established listing of codes for the data. Additionally, all of these data were input into NVivo® within a reasonable time after the researcher obtained them. The significance of this timely processing turnaround becomes evident as secondary data sources are considered.

**PRIMARY DATA SOURCES**

Great care was given to analyzing each data source. First, survey questions and the corresponding Likert-scale answers were added to NVivo® under the participant’s set of documents as they became available. Second, audio-tapes were analyzed on an on-going basis as the supervisory meetings were completed. The researcher listened to the audio-tapes prior to transcription. As Maxwell (1996) explains, “listening to interview tapes prior to transcription is also an opportunity for analysis” (p. 78). Finally, the researcher transcribed the tapes and input the text to NVivo® for further analysis. Third, reflection logs were obtained electronically by the researcher on an ongoing basis, translated into rich text format, and placed into NVivo®. Fourth, interview audio-tapes were translated into text in NVivo® using the same procedure as with college supervisory meeting audio-tapes.

Data analysis also involved a form of member-checking. Member-checks systematically solicit feedback from participants about one’s data and the conclusions one is drawing (Maxwell, 1996). Research participants were given the opportunity to read and comment on the texts of their audio-recorded college supervisory meetings and semi-structured interviews.

**SECONDARY DATA SOURCES.**

In NVivo®, secondary data sources are those that the researcher created from information that emerged from the primary data. Secondary data sources include memos used to record personal interpretations and thoughts about the data, a methodological log where a record was kept of how the researcher navigated through the project, reflection logs where ongoing thoughts and questions were recorded, and visual NVivo® models that helped the researcher illustrate and analyze emerging relationships among data, in addition to emerging themes and patterns.

In NVivo®, participant documents were maintained as separate entities called case nodes, yet were linked with each other through coding, linking with other data, and the use of sets. For example, memos
were linked with related documents using NVivo®'s features. Documents or research that was particularly pertinent to the study were scanned or imported into the project. The visual modeling feature of NVivo® was used on a consistent basis to develop evolving visual models of relationships between data or of phenomena that emerged.

**ANALYSIS OF FOUR SOURCES OF EFFICACY INFORMATION**

Using the 1998 Tschannen-Moran et al. cyclical model of teacher efficacy beliefs (shown in Figure 2) as a guide, the researcher examined the primary data sources collected in this study and identified and coded the examples of the four sources of efficacy information.

The four sources of efficacy information, originally proposed by Bandura (1997), were pre-established codes entered into the NVivo® software by the researcher even prior to the beginning of the study, as part of her NVivo® Shell. The sources of efficacy information as titled in the Tschannen-Moran et al. (1998) model, and throughout the remainder of this paper, were verbal persuasion, vicarious experience, physiological arousal, and mastery experiences.

**A SUMMARY OF FINDINGS**

**SUMMARY OF TEACHERS’ SELF-EFFICACY BELIEFS**

Teachers’ self-efficacy beliefs are “a little idea with big impact” (Tschannen-Moran & Woolfolk Hoy, 2002, p. 7). The teacher self-efficacy beliefs of three career-change mathematics teachers were studied and the role that college supervision played in the process of the construction of those beliefs was examined. Data from this study suggest that indeed, teachers’ self-efficacy beliefs are important in the development and sustainability of their performance as a teacher, and that a college supervisor plays a role in guiding this development.

The college supervisor, as expected based on the traditional clinical role described in the literature, primarily addressed instructional efficacy. This study highlighted that it was important for the college supervisor to provide and acknowledge a variety of the four sources of efficacy information, in a proportion appropriate to the individual needs of each teacher. The supervisor did not have the benefit of having the results of the raw data collection used in this study, and yet showed skill in assessing teachers’ beginning efficacy beliefs, providing the feedback necessary, and considering the way each teacher processed the information she gave to them. Ultimately each teacher adjusted his or her teacher self-efficacy beliefs to achieve optimal performance, as indicated by the analysis of the survey instrument responses. The teachers indicated in their final interview that they were satisfied with their new career and that they intended to remain in the profession. This feedback suggested that the issues of teacher attrition and teacher turnover, which are the overarching issues addressed by this study, were ultimately influenced by the construction of teachers’ self-efficacy beliefs. College supervision as provided in this alterna-

tive certification program contributed in some way to this process and the teachers’ intention to remain in their new teaching careers.

In each of the three participants' instances, the supervisor provided some form of support to the participants. As shown in Table 2, verbal persuasion was the primary source of efficacy information for Chantal and Tiffany, the two female middle school mathematics teachers. Vicarious experience, with the use of transparencies, was the primary source of efficacy information for Justin, the male high school mathematics teacher.

In this study, the role of the college supervisor, as viewed from the perspective of the participants, seemed to be of a supportive nature, whether verbal or resource support. The supervisor fulfilled the traditional observing-conferencing role expected by the college, but to the participants, the role’s value seemed to be of a more personal nature. Additionally, two of the participants mentioned the college supervisor’s value as an impetus to being organized about lesson planning. One of the participants mentioned the importance to him about the use of transparencies in the classroom as a teaching tool which then had an impact on student understanding, classroom management, and time for teaching.

The uniqueness of each individual teacher participant means that the participants’ perspectives of the role the supervisor plays are also unique to them and their particular needs, strengths, and deficiencies. As previously described, each teacher participant received tailored sources of efficacy information from the college supervisor, cognitively processed those sources differently, and emerged from their college supervisory experiences with changed but differing views of the teaching tasks they faced and their assessment of their own teaching competence. By examining the aspects of how the teacher participants cognitively processed the different sources of efficacy information, themes emerged through NVivo® data analysis, and the researcher discovered common issues across participants. These emergent issues were not meant to generalize these data to larger populations, but could be important for considering future research.

Each participant emerged from their college supervisory experiences with responses and directions based on their cognitive processing of the aspects of sources of efficacy information during Spring 2005. Each participant’s responses in their own words are illustrated in Figure 3 which represents all three participants and highlights the overlap and commonality found among the participants. Data from this exercise suggest that the supervisor played a supportive role for each of the participants and also served as a resource for practical ideas for use in the classroom.

This study further suggested that, in accord with the Tschannen-Moran et al. (1998) model, the supervisor contributed to each teacher’s individual analysis of the teaching task and used support to improve their assessment of personal teaching competence. However, this study did not specifically address these two aspects.

<table>
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<th>Source of efficacy information</th>
<th>Data Gathered From</th>
<th>Verbal Persuasion</th>
<th>Vicarious Experience</th>
<th>Physiological Arousal</th>
<th>Mastery Experience</th>
<th>Total number of instances of all sources of efficacy information</th>
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<td></td>
<td>College Supervisory Meetings</td>
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<td>f</td>
<td>% of total</td>
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<td>33%</td>
<td>42</td>
<td>37%</td>
<td>9</td>
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<tr>
<td>Tiffany</td>
<td>College Supervisory Meetings, Reflection Logs, Final Interview</td>
<td>61</td>
<td>46%</td>
<td>21</td>
<td>16%</td>
<td>19</td>
</tr>
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</table>

Table 2
The frequency and percentage of the total of instances of all sources of efficacy information for each participant. This table is based on the analysis of three sources of data: transcripts of college supervisory meetings, reflection logs, and the final semi-structured interview with the researcher.
of the Tschannen-Moran et al. (1998) model. Each teacher improved in some areas and may have become more realistic in others, strengthening their teacher self-efficacy beliefs and impacting each participant’s stated intent to remain in the profession. Assessing the performance of the teachers was not the purpose of this study, but it can be reasonably suggested that each person’s performance, even without the continued presence of the college supervisor, will provide new sources of efficacy information.

**Findings**

In view of the discussion of this study, findings or assertions emerged that answered the primary question of this study. This study questioned, “What is the role of college supervision as a factor contributing to the construction of teacher efficacy beliefs of new career-change mathematics teachers in an urban setting?” In response, the researcher can clearly assert based on the perspectives of the study participants, that the role of the college supervisor was primarily supportive and advice-giving in nature for these new career-change mathematics teachers in urban settings. On an individual basis, the role of the college supervisor was tailored to meet the needs, personality, and existing efficacy beliefs within each teacher’s social milieu and school climate, and was based on the teacher’s developing instructional efficacy beliefs. This was skillfully accomplished by the college supervisor to bring each individual to an optimal level of competence.

The findings of this study also suggest that the study participants’ teacher self-efficacy beliefs at the end of their college supervisory experiences will help them stay in the teaching profession. Each participant indicated their intent to remain in the teaching profession. Although this intent cannot be solely attributed to their efficacy beliefs, or the college supervision they received, the interview data suggested that each of the participants is armed with the confidence to orchestrate the skills (Bandura, 1997; Valiente, 2004) necessary to be a teacher and to be satisfied in their new career. This assertion speaks to the overarching purpose of this study which was to address teacher attrition and turnover.

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**Participants’ Responses to College Supervision**

*CHANTAL*
Primary Source of Efficacy Information: Verbal Persuasion

- Comfortable
  - Figured out a lot on my own
  - Gave me impression I had done a good job
  - I was well-prepared
  - Interaction with students
  - Nothing negative
  - Surprised
  - Reinforced
  - Logistics

- Support
  - Ideas/Advice

- Organize

*JUSTIN*
Primary Source of Efficacy Information: Vicarious Experience

- Liked meetings
- Mentor
- Role is important
- Transparencies
- Good experience
- An extra eye

- Complimented me
- Discussion
- Felt sense of accomplishment
- Confidence!

*TIFFANY*
Primary Source of Efficacy Information: Verbal Persuasion

*Figure 3.* The perspectives of each participant on their responses to college supervision, and the perspectives common to all three.

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CONCLUSIONS AND DISCUSSION

The outcomes of this study are in support of the idea that teacher self-efficacy beliefs influenced by the college supervisor are important to retaining career-change teachers in the profession. The study points to the different perspectives of the career-change teachers who receive the college supervision and the skill required by the college supervisor in tailoring feedback to address the needs of the teacher at any particular time and during a variety of situations. Participants viewed the college supervisory experience as valuable, albeit in different ways. In each case, the college supervisor played an important role in the construction of the new career-change teachers’ self-efficacy beliefs in their schools and teaching careers. Implications exist for practice, research, and theory and for teachers, schools, districts, and colleges and universities. Indeed, the notion of teacher self-efficacy beliefs is “a little idea with big impact” (Tschannen-Moran & Woolfolk Hoy, 2002, p. 7).

References


Operationalizing School Culture: Transforming Big Ideas Into Systems and Structures: Lessons From Three High-Performing Urban Charter Schools

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ABSTRACT

Leadership and school culture are essential ingredients of high-performing schools. Reform efforts such as the No Child Left Behind Act (2001) have increasingly placed demands on school leaders to ensure the success of their schools. This has created great challenges for school leaders, in particular, those who lead in urban schools. Charter schools are an increasingly growing phenomenon and have been identified as a reform effort that offers great hope for improving the quality of urban education. This paper draws from data collected in a qualitative dissertation study (Donohoe, 2006) which explored the role of leadership in shaping school culture within three high-performing urban charter schools in Massachusetts. This paper focuses specifically on the ways in which school leaders can operationalize school cultures that support students' academic performance by transforming big ideas into systems and structures that support five organizational constructs: leadership, curriculum and instruction, behavioral expectations, relationships and professional development.

On a very basic level, high-performing means that each of these schools is outperforming schools in their district as well as across the state. However, the success of these schools is much greater than a test score. Performance is also both driven and measured by students' ability to gain acceptance to institutions of higher education, a world which previously had seemed out of reach for many students who attended low-performing urban schools. For example, the Academy of the Pacific Rim, the oldest of the three schools, has graduated four classes of seniors since it opened its doors in 1997. Of these graduating classes, 100% gained acceptance to an average of at least four colleges or universities, and 85% of the graduates from the classes of 2003, 2004, and 2005 are currently matriculated at four year colleges and universities while 5% are attending 2 year schools. In 2006, 100% of the graduating class gained acceptance and matriculated in four year colleges and universities (The Academy of the Pacific Rim Annual Report 2006).

In 2006 Excel Academy graduated its first eighth graders of whom 75% gained acceptance to college preparatory high schools including, the Commonwealth School, Boston College High School, Boston Latin, Pingree and St. John’s Preparatory School. In addition, Excel Academy graduates were awarded $644,000 in financial aid to attend the private, and parochial schools to which they were accepted. This group of eighth graders had outperformed students from nearly every part of the state on the 2006 MCAS exam and had placed themselves in the top 9% statewide on English and in the top 6% state-wide on math (www.excelacademy.org). At the time of this dissertation study, Boston Preparatory Public Charter School was only in its second operational year and while students at Boston Prep were making great academic strides and were outperforming other schools in its district and across the state (www.bostonprep.org), Boston Prep had not yet experienced success through its graduates. Quite simply, Boston Prep had had not been open long enough to see the actualization of its college preparatory mission, yet the anticipation of achievement could be felt in the hallways that displayed college banners that read “graduates of 2015.” College may be in the distant future for the sixth and seventh graders of Boston Prep, however they practiced college interviews which were

Victor Hugo, a 19th century author, believed that there is nothing more powerful than an idea whose time has come. School culture is now on the agenda of many educational leaders and demonstrated in the literature is the power of such an idea whose time has come. School culture has continuously been identified as an essential ingredient in school improvement and is consistently identified as being an instrumental factor in improving student achievement, teacher performance, student and staff participation in school events, attendance, graduation rates, parental satisfaction, and overall sense of community within the school (Cotton, 1996; Klonsky, 2002; Lee, 2001; Meier, 1996; Wasley et al, 2000).

As educational leaders are continuously challenged to engage in reform efforts to improve their schools, it is critical that school culture receives the attention that it deserves. Additionally, it is also essential to explore the role of leadership in creating, cultivating, shaping, supporting, and sustaining school cultures that support students’ academic performance. In Boston, Massachusetts, the Academy of the Pacific Rim, Boston Preparatory Public Charter School, and Excel Academy, all which are high-performing urban charter schools, have been recognized for not only their strength in leadership, but also for their strong school cultures that support students’ academic performance.
videotaped and visited college campuses as part of an effort to lay the groundwork for preparedness and future success. If one thing was clear, these students were preparing for high school, college, and a world filled with opportunity and possibility. See Figure 1 that displays a bulletin board at Boston Preparatory Charter School.

The continued growing and evolving success of these three schools speaks loudly and clearly of the impact these schools are having on transforming the educational experience of students who previously were limited by the lack of opportunity and choice in their under-performing urban districts. In a qualitative dissertation study that closely examined the leadership and culture of these three high-performing urban charter schools through document analysis, observations, the collection of visual data and interviews, data suggested that while culture is founded on big ideas, it is purposefully constructed through systems and structures which are essential to the day-to-day functioning of a school. These systems and structures become vehicles which operationalize the culture of schools (Donohoe, 2006).

WHAT IS SCHOOL CULTURE?

The culture of a school is complex, continuously changing, and emerges from a collection of assumptions, beliefs, values, and expectations that are formed over time. The culture of a school is evidenced through attitudes, behaviors, practices, perceptions, and artifacts which shape the collective understanding of the organization that are often simply referred to as “the way things are done around here” (Deal & Kennedy, p. 4).

The complexity of the concept of school culture is reflected in the multitude of ways that it is defined. Hargreaves and Fullan (1996) describe school culture as the guiding beliefs and expectations that are evident in the way a school operates, more specifically in reference to how people relate to each other. This foreshadows the importance that relationships play in culture. DuFour and Burnette (2002) include in their definition of school culture “the assumptions, habits, expectations and beliefs of the staff” (p. 1), which suggests the importance of values and beliefs.

Bolman and Deal (1997) expand the understanding by explaining that “culture is both product and process” (p. 217). As a product it embodies the accumulated wisdom from the past. As a process it is continually renewed and recreated as newcomers learn the old ways and eventually become teachers themselves. Schools as organizations typically have identities that are clearly evidenced by these patterns of behaviors, thoughts and norms of members of the school community. School culture, as a concept, aids in understanding these patterns, more specifically, what they are, how they developed and how they affect performance (Deal & Peterson, 1999). This hints at the relationship between culture and performance.

While the concept of school culture remains complex, it is not a new term to educational literature. Sarason (1971) described school culture as an important vehicle for redefining and resisting educational initiatives. He espoused the belief that the existing setting or culture of a school defines the permissible ways in which goals and problems will be approached. However, over the past several decades there has been increasingly growing attention given to organizational culture as a construct to analyze schools, and this can be attributed to the explosion of literature on corporate cultures and its role in improving performance (Hoy, 1990). Schools, like the corporate world, are ultimately striving to improve their performance.

BEGINNING TO OPERATIONALIZE SCHOOL CULTURE

Once school leaders have recognized, embraced and understood the complexity and importance of school culture, where do they start? How do they begin to translate their lofty ideas about the ways in which they envision their schools, into systems and structures that will shape, support and sustain these desired school cultures? School leaders who have begun to harness the powers and possibilities of a strong school culture often credit both the commitment and patient perseverance in their efforts to operationalize the culture of their schools (Donohoe, 2006). What does it mean to operationalize school culture? Simply stated, it is taking the ideas, beliefs, and assumptions which are the foun-
dation of culture and translating them into clearly stated objectives and systems that can be implemented and measured through the development of clear roles and expectations for all members of the school community. Simply stated, not always easily accomplished.

LESSONS FROM THREE HIGH-PERFORMING URBAN CHARTER SCHOOLS

Figure 2 depicts the traits of the school culture that emerged from data collected in a qualitative dissertation study which explored the role of leadership in shaping school culture in high-performing urban charter schools (Donohoe, 2006). The three schools participating in this study were the Academy of the Pacific Rim and Boston Preparatory Public Charter School, both located in Hyde Park, Massachusetts and Excel Academy, located in East Boston, Massachusetts. Figure 2 provides a starting point for understanding the ways in which school cultures move from complex and ambiguous concepts into a flexible framework of understanding that can be applied to schools within different contexts. While the diagram depicts traits as individual aspects of the cultures found at these schools and suggests a sort of sequential hierarchy, it is critical to understand the interconnectedness and overlap of these mutually reinforcing traits.

The foundation of each of these schools’ cultures was grounded in shared beliefs and a shared mission. Shared beliefs and missions are the “big ideas” that anchored the entire schools’ existence. They were the guiding principles, the foundation and the framework from which all constructs were built. In these particular schools it was the belief that all kids could learn and achieve at high levels and this was met with a clear, college focused mission for all students. This foundation was followed by and solidified by creating and establishing clarity of roles and expectations and by developing systems and structures to support these roles and expectations. Simply stated, clarity of roles and expectations coupled with systems meant articulating who was responsible for what and how they were expected to do it, and creating systems supported these roles and facilitated the fulfillment of expectations. This included expectations for school leaders, teachers, staff, students, families and members of the community.

This clarity removed the guess work and eliminated ambiguity which can often lead to chaos and confusion in schools. The success of these systems was evidenced by the emergence of a climate of safety and a shared language and was further systematized through establishing rituals and routines. The climate of safety was a direct result of clear expectations and systems to support this. For example, at each of these schools there were clear behavioral expectations for students. These expectations were clearly stated, and there were also systems within each and every aspect of the school day that supported these expectations. Expectations were more than fancy rhetoric; they were alive and integrated throughout the daily life of the school. Each of the schools had established their own shared language in regards to what was expected and valued, and this language was used as a system to support the expectations.

At the surface, the culture of a school is evidenced by the behaviors. When most people think of culture, they immediately define it by the way a group or organization behaves and interacts with one another and with those outside of the community. At each of these schools behavior was essential to creating their desired cultures and therefore a priority was given to establishing rituals and routines that supported positive behavior. In addition each of these schools gave great attention to the powerful role symbols play in supporting a culture. This was demonstrated through powerful displays exhibited on bulletin boards, classroom walls, and throughout the school.

TRANSFORMING THINKING INTO PRACTICE

With a basic understanding of the traits of each of these high-performing schools’ cultures, we can now move from thinking conceptually about operationalizing school culture to thinking practically about the ways in which we can begin to operationalize school cultures in a variety of settings and contexts. Bolman and Deal (1997) explained the importance of structures and identified them as the connecting glue between values and behaviors. At the Academy of the Pacific Rim, Boston Preparatory Public Charter School, and Excel

![Figure 2. Traits of school culture found in high-performing schools](image-url)
Academy, there were purposely defined structures and systems that established consistent routines and rituals that operationalized the mission of each of these schools.

In attempts to bring clarity to chaos, we will look to the Venn diagram in Figure 3 which depicts five organizational constructs that can be utilized by leadership as vehicles to implement structures and systems that shape a school culture (Donohoe, 2006). These constructs are leadership, curriculum & instruction, behavioral expectations, relationships, and professional development. While these constructs have many unique qualities and specific foci within the life of a school, it is the interconnectedness of these constructs and the leadership's awareness of this that allows for creating a culture that supports students’ academic performance and capacity building.

Goldring (2002) discussed observable aspects of culture as the way in which space and time are organized. At the Academy of the Pacific Rim, Boston Preparatory Public Charter School, and Excel Academy, all high-performing urban charter schools in Massachusetts, well-thought out and clearly defined systems and structures emerged from these constructs and demonstrated the ways in which space and time can be organized to support the academic performance of students. These structures and systems not only supported each construct, but clearly outlined what it should look like in action, how it would be accomplished, and clearly defined all expectations.

The existence of these constructs alone did not create or sustain these high-performing schools. These constructs were part of a larger system and were only as strong as the leadership, which initiated, implemented, encouraged and held the community accountable to these systems and structures. This required patience, persistence and the creation of collective consistency. These systems and structures were also supported through dialogue and the establishment of a common language, through reflection focused on continuous improvement, and most importantly through engagement in the ongoing struggle which is inherent in the pursuit of excellence and a willingness to wrestle with the many complexities of life within an urban school.

**OPERATIONALIZING CULTURE WITH SYSTEMS AND STRUCTURES**

In the examination of these three high-performing urban charter schools; leadership was essential to shaping school cultures that supported students’ academic performance. In addition to being the link between the forces that drive the culture of a school and the actual shaping of the culture, leadership also emerged as a construct itself within each of the schools. Leadership was a vehicle that shaped, supported and sustained the cultures of these schools. As a construct, leadership was not only the vehicle; it was also the guiding ideas and conceptual frameworks of leadership, the ways in which it was defined, and the way these ideas and beliefs about leadership were structured into the daily life of a school of these schools.

**THE CONSTRUCT OF LEADERSHIP**

The Academy of the Pacific Rim, Boston Preparatory Public Charter School and Excel Academy, all had well-defined leadership structures which included clearly defined roles for all members of the leadership teams. All three schools had an Executive Director, Principal, Dean of Students and Dean of Curriculum. Each of these school leaders had very specific responsibilities and strengths which collectively shaped a strong

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*Figure 3. Organizational constructs of school culture*
leadership team. The Executive Director was primarily responsible for the “big picture” which included maintaining mission alignment, establishing partnerships within the community, ensuring compliance with federal and state regulations, cultivating fundraising opportunities, and engaging in other long-term planning efforts.

The Principals were the day-to-day leader within each of these schools. He or she was responsible for overseeing the schools mission in the minute-by-minute interactions and events of the life of the school. This included everything from greeting students, parents and faculty at the start of the day, making sure students are where they need to be and that faculty have what they need to support their instructional efforts. The Deans of Students were responsible for supporting the behavioral expectations within the schools which were often referred to as discipline or the student conduct code. The Deans of Students worked closely with the principal, faculty members, and families. The Deans of Curriculum focused primarily on curriculum and instruction and partnered with faculty to design lessons and support systems that fostered student learning and aimed to improve overall student performance. While each of these school leaders had different responsibilities, they worked collaboratively and consistently identified supporting the schools’ shared missions as their top priority.

The Department of Education’s National Study on Charter Schools (1998) conducted by RPP International identified that schools with strong management and leadership structures and strong agreement about the school’s vision among parents, teachers, and staff have fewer internal difficulties. The Academy of the Pacific Rim, Boston Preparatory Public Charter School and Excel Academy evidenced the importance of creating leadership structures that are supported by clearly defined roles and responsibilities. At each of these schools these structures and mission alignment were often credited with minimizing internal struggles.

**The Construct of Curriculum and Instruction**

Curriculum and instruction as a construct within these schools was the conceptualization and organization of knowledge bases and pedagogy. It included ideas and beliefs about curriculum and instruction and was a vehicle used by leadership to shape, to support, and to sustain school cultures that supported students’ academic performance. At the Academy of the Pacific Rim, Boston Preparatory Public Charter School and Excel Academy the foundation of the curriculum was college preparation and was guided by the firmly held and non-negotiable belief that all kids can learn and achieve at high levels.

At the Academy of the Pacific Rim, Boston Preparatory Public Charter School, and Excel Academy, space and time were purposely organized to support the mission of each of the schools. All three of these schools had an extended school day and school year, which included on average, 190 day school year, 8 hour school day, mandatory Saturday Academies for students who are failing core academic subjects, several hours of homework each night, and mandatory after school homework centers for students who do not complete their homework. When school leaders were asked, the answer was simple, “Our kids are behind from the beginning and that simply requires more time.”

The Academy of the Pacific Rim serves grades 6-12 and is deeply committed to a rigorous academic curriculum. School leaders are proud that they offer only one, accelerated college preparatory program. There are no options for courses at any level and students must pass all their classes with an average of 70% or higher. During students’ seven years at the Academy of the Pacific Rim, they read Shakespeare, write analytical essays, examine primary sources, and solve abstract mathematical problems. They read, write and speak Mandarin beginning in the 7th grade. All students take Algebra in the 8th grade. Once in high school, students take four years of English, math, science, history and Mandarin.

Boston Preparatory Charter School currently serves students in the 6th, 7th and 8th grade. Boston Prep is an affiliate of the Academy of the Pacific Rim and therefore has attempted to replicate the Academy of the Pacific Rim, sharing the deep commitment to providing urban students with a highly rigorous academic, college preparatory curriculum. In fact, the Executive Director of Boston Prep, Scott McCue, is a former administrator of the Academy of the Pacific Rim, and the early blueprints of Boston Prep were crafted in an effort to expand upon the successes of the Academy of the Pacific Rim and to bring opportunity and hope to the many families who were finding themselves on the growing waitlists at the Academy of the Pacific Rim without another choice for a high-performing school for their children.

The support for such replication was evidenced with the signatures of over 700 parents who wanted more for their children and who believed in the power of an academic curriculum supported by character education and recognized that it would give their children what the public system had failed to do, exponentially increased opportunities for life, college and beyond.
While the curriculum at Boston Prep is similar to the Academy of the Pacific Rim, it distinguishes itself with refinements, including enhanced supports for learning, an all-inclusive enrichment program, and a New England-based school ethos inspired by thinkers such as Ralph Waldo Emerson, W.E.B. Dubois, and Maria W. Stewart.

Excel Academy is a middle school which serves students in grades 6-8. The curriculum at Excel Academy is grounded in the school’s mission, which is “to prepare middle school students to succeed in high school, to apply their learning to solve relevant problems, and to engage productively in their communities.” This is accomplished by organizing the curriculum into four areas: core, connections, focus, and enrichment. Core addresses the core skills and content necessary for success in high school and college. At Excel Academy, students take 100 minutes of Mathematics and 100 minutes of English every day. Connections allow students to gain core skills in the scientific method and geography and explore questions that relate to their communities but also possess a global significance. Each day the students at Excel Academy engage in 50 minutes of science and 50 minutes of social studies to gain these competencies. Focus is a time in which students receive targeted tutoring and academic support focused on individual needs throughout the week. Enrichment is a period within the school day that provides students with instruction in the arts and fitness and also provides student the opportunities to participate in other enrichment activities.

The way in which classrooms were organized also evidenced structures and systems that supported both the mission and curriculum of each of these schools. This was most evident at Boston Preparatory Public Charter School and Excel Academy where they shared the same structures and systems in every classroom which created a consistency from classroom to classroom. See Figures 4 and 5 for systems utilized within classrooms at Excel Academy. In Figure 4 Excel Academy’s binder system is displayed. This is a place where students store their binders which they use in each class. Above the crates are lists for each break time during the day and what students should have ready. In Figure 5 the Noise Odometer is displayed. This was a tool used to make explicitly clear what the expectation was for noise level. This was used in classrooms and for school-wide assemblies and meetings.

Drucker (2002) and Sarason (1996) consistently suggested that intended outcomes be stated in overt behaviors. The clarity of roles and expectations within the systems at The Academy of the Pacific Rim, Boston Preparatory Public Charter School and Excel Academy, allowed for outcomes to be measured by observable behaviors. For example, at both Boston Preparatory Public Charter School and Excel Academy classroom lessons began with stated objectives that were displayed for all to see and a “do now” activity which was a quick exercise to focus the students on the lesson of the day. For example, in math classes, the “do now” often included several challenging problems that may be a review of material students had been working on or an introduction of new concepts and then ended with what was called a “mad minute” in which students raced to complete a series of quick math problems. Each lesson ended with a review of the objectives as well as the ways in which student behavior demonstrated the school’s expectations. This was specific and clearly connected values with behaviors. This removed the confusion and chaos that can result from what Sarason (1996) calls the un-testable abstraction, which refers to expectations that exist without specific criteria that can be used to consistently measure these behaviors.
THE CONSTRUCT OF BEHAVIORAL EXPECTATIONS

Behavioral expectations as a construct included beliefs and ideas about standards of behavior for all members of these school communities. This construct expanded beyond simply behavior management and student discipline and moved towards cultivating a culture that is grounded by clarity of expectations for all interactions within the daily life of the school.

Deal and Peterson (1999) discussed how rituals, routines and ceremonies represent what is valued and important within a school culture and this was exemplified at the Academy of the Pacific Rim, Boston Preparatory Public Charter School and Excel Academy. For example, at each of these three schools there was a “call to order” to signal the start of class. This was a ritual in which the teacher would command attention simply by raising their hand. Students without encouragement, would collectively rise and stand behind their desk. The teacher would initiate the call by saying, “good morning California State (or whatever the name of the homeroom was)” and the students would respond in unison, “good morning Ms. Smith” mimicking the inflection of the teacher. Students would then take their seats. Class had begun. This simple routine evidenced the value of order as well as a sense of urgency.

At the Academy of the Pacific Rim, students and staff greeted each other with the traditional “handshake” which evidenced mutual respect and an expectation of professionalism. At the Academy of the Pacific Rim and Boston Prep, students were greeted each morning as they stepped off the bus by their executive director, who shook the hand of each student and asked, “Are you ready to learn?” At Excel Academy students were also greeted by school leaders. At the moment Excel students walked in the front door, they were greeted with a “good morning” accompanied by a quick uniform inspection. This was a swift and routine process that flowed like a well-rehearsed dance step. Once students passed the uniform inspection, the focus immediately switched gears to academics as the students were challenged to use the word of the day in a sentence. The word of the day was displayed on an easel and this was an activity that students and faculty all seemed to enjoy.

At Excel Academy and Boston Prep there were systems in place that integrated the values of the schools into the expectations within classrooms. At Excel Academy, each class ended with the “Building Block Challenge” which reviewed students’ behavior defined by the school values of PREP (prepared, respect, engaged, and professional) and awarded the class as a collective whole, a letter representing each value they demonstrated throughout the class. For example, if all students in a particular class were prepared, which meant having the materials they needed for class, having their homework completed, and being ready to learn, the teacher would let the class know that they had earned their “P” for being prepared. See Figure 6 which is a photo of the Building Block Challenge classroom board at Excel Academy.

At Boston Preparatory Public Charter School, class ended with the “Five for Five” which provided students with direct feedback on how their performance and behavior evidenced the schools expectations. The “five for five” assessed students’ behavior making connections to the schools virtues of courage, compassion, integrity, perseverance, and respect. At Excel, the “Building Blocks”, like the “five for five” at Boston Prep, were an integral part of every class and reviewed at the end of each class period. Throughout the school points were tallied in a school-wide competition. Over time, these rituals become what Sarason (1996) called behavioral regularities, which are routine behaviors that become unquestioned after consistent repetition.

THE CONSTRUCT OF RELATIONSHIPS

Relationships as a construct included the ideas, beliefs and values in regards to the ways in which members of the school communities interacted and the types of relationships that are fostered and developed over time. Relationships are consistently identified as an essential ingredient of effective leadership (Bolman and Deal, 1997; Fullan, 2001; Goleman, Boyatzis and McKee, 2002) and are also identified as a springboard

Figure 6. Photo of Excel Academy’s Building Block Challenge
from which school culture emerges (Deal and Peterson, 1999; Goldring, 2002; Meier, 1996). At the Academy of the Pacific Rim, Boston Prep and Excel Academy, relationships are a work in progress. They are ongoing, not static. Relationships are open dialogue that has no end. Relationships are the fabric that weaves the complexity of the daily lives of those within these school communities together and promote engagement resulting in a cohesive school culture.

At each of these schools there was a strong value on relationships building and this included interactions between school leaders and faculty members, faculty members and faculty members, faculty members and students, school leaders and families, faculty and families, school leaders and students, school leaders and faculty and community members, and students and the community. The strong value on relationships was much more than fancy rhetoric; it was a value and essential ingredient of the schools’ success which was operationalized through systems that supported this value. Relationships are created, cultivated, supported, shaped and sustained through events such as school ceremonies, traditions, rituals and are reinforced through symbols, behaviors and artifacts.

On a very fundamental level, structures and systems that supported relationships were simply the ways in which members of the community were organized. For example, at each of these schools, students were organized by homerooms or advisory groups which created systems for relationship building to support both curriculum and instruction. This created opportunities for students to connect and feel part of a group or team as well as to establish a relationship with an adult outside of the classroom. Each of these homerooms or advisories was named after a college or university which operationalized the college focused missions by incorporating these missions into the daily life of the schools and to the identity of these student groups. Students were not members of homeroom 6A; they were members of California State, MIT or Boston College. This was powerful. The visibility of names of colleges and universities served as symbols to all members of these school communities of their future destination and integrated the idea of college into a shared language at each of these schools.

Strengthening relationships among faculty members was also greatly valued, supported and encouraged. At each of these three schools, faculty did not have their own classrooms. There were faculty rooms where all teachers had a desk and a computer. The structured of this shared space was often credited for creating opportunities for “teacher talk” and sharing that may not happen if they were isolated in their own classrooms. At each of these schools, faculty participated in “all faculty meetings” that took the form of active dialogue and healthy debates about the issues the schools were facing. The leadership at each of these schools recognizes the importance of both dialogue and reflection as essential to sustaining relationships and school culture, which results in a collective consistency. Of course, unless a visitor attended or participated in these meetings at each of these schools, he or she may never witness the struggle within these schools’ pursuit of excellence. Dialogue is essential for relationships and progress.

There are numerous examples of the ways in which systems and structures supported and sustained relationships at each of these schools. For example, at the Academy of the Pacific Rim, there was a faculty mentoring program that partnered new faculty members with veteran faculty members to provide opportunities for collaboration, support, and relationship building. At Boston Prep, students participated in weekly advisory groups that explored and discussed the schools’ values which were supported by Boston Prep’s Ethics Curriculum. This provided students the opportunity to discover the importance of understanding their role in their community and to begin to explore what it means to be a “good human being.” At Excel Academy, which had a detailed conduct code supported by a comprehensive system of merits and demerits, there was a “respectful disagreement clause.” This meant that at any time students could politely say, “I respectfully disagree and would like to discuss this later.” This did not mean that students would not be responsible for their behavior, but it did honor the importance of dialogue as part of the process of both learning and relationship building.

The Academy of the Pacific Rim, Boston Preparatory Charter School, and Excel Academy all value the importance of building and sustaining relationships with the families of their students. These relationships were established early through partnerships with parents that were formed in the early planning stages of each of these schools. Each of these schools had gained the support of families in these communities and has sustained them over time. The families of these three schools were not viewed as constituents that needed to be dealt with, but were viewed as partners in their pursuit of excellence. Each of these three schools had established websites that had detailed information for families. In addition, there were up-to-date homework telephone lines that allowed parents to call in to hear what their student had for homework and there were newsletters that went home either bi-weekly or month-
ly to families in both English and Spanish. In addition, there were weekly calls to families from their student's advisor, who informed families of how their student was doing academically. These calls allowed for connections to be made on a regular basis and were not only to report something negative. There were also parent meetings and parent councils. Again, dialogue was essential to relationship building.

Angelides and Ainscow (2000) discuss the power of relationships and identify the power of "critical incidents" in shaping school culture and fostering relationships. At the Academy of the Pacific Rim, Boston Prep, and Excel Academy, relationships with families were not only cultivated through formal and planned interactions. At each of these schools leaders greet students as they arrive. It is not an exaggeration to say that this is probably the most important half-hour in a school leader's day. This creates an opportunity for families to connect with school leaders informally and invites opportunities for interactions with almost every member of the school community before the day has even begun. These informal and unplanned interactions demonstrated the power of "critical incidents" that helped to define the culture of each of these schools.

A grandmother of a student at the Academy of the Pacific Rim explained that "Mr. Blasdale (the executive director) greets the kids each morning with a handshake. He is a good man. If I have a question, when I drop the kids off, I can just ask him. This school has saved my grandchildren and will give them a future." At Boston Prep, a father and his son, who had recently gained admission for the next year in the school's annual lottery, were touring the school. In conversation, the father said, "this school is bright and welcoming. I have never been invited to walk around and see what my son's school will be like. The teachers work hard here, and after meeting with them, I think they are going to help me too. This school is going to be hard, but I want that for my son." At Excel Academy a number of parents came into the school to speak to either the principal or the executive director at the start of the day. As they entered the building, they walked with confidence as if they knew they were welcomed because they believed this was their school too. After all, why would they not feel comfortable when the start of the day was structured to give them immediate access and to honor their presence as a welcomed interruption. All of these "critical incidents" were instrumental in creating partnerships with families.

**The Construct of Professional Development**

Professional development as a construct included the ideas and beliefs that guided professional development and the ways in which it was integrated into the culture of these three schools. At the core, professional development serves as a vehicle to strengthen relationships and to foster commitment to the school through continuous involvement and growth. Essential to each of these three schools was their shared vision. Professional development is a tool that can be utilized to support, and sustain a school's vision (Barth, 1990; Elmore, 2003; Fullan, 2001). At the Academy of the Pacific Rim, Boston Prep, and Excel Academy, professional development is an essential ingredient in their success and is an integral component of their continuous effort in pursuit of excellence. Professional development at each of these schools is not an annual workshop sponsored by the school; it is an ongoing effort that is structured into the daily life of each of these schools.

At the Academy of the Pacific Rim there was a variety of way in which professional development was structured into the school as an organization. Over the years the Academy of the Pacific Rim had grown into a school serving students in grades 6-12. This required the leadership structure to change over time. As the school grew, it transitioned from a school with one principal to a school with two principals, one for the middle school and one for the high school. This change required not only a different structure, but also support for this new structure. The former principal, who left her full-time position after the birth of her child, now served as a leadership mentor for the two new principals. This created a support structure that was founded on experience, historical knowledge of the school, as well as the recognition that even school leaders need mentors and an opportunity to grow and develop.

The Academy of the Pacific Rim structured both formal and informal opportunities for professional development. It was already mentioned that faculty did not have their own classrooms and shared space in a faculty room. This structure not only created opportunities for relationship building, but also opportunities to engage in informal “teacher talk” which allows for professional development through thoughtful dialogue and reflection. At the Academy of the Pacific Rim, there were a number of school-wide initiatives that were born in discussions that took place in the faculty room.

The Academy of the Pacific Rim also greatly valued structured time committed to professional development. This value was operationalized by organizing the
school's schedule to allow for students' early release on Wednesdays and faculty and staff were in structured meetings from 3pm-5pm. The first hour was dedicated to departmental meetings and the second hour was dedicated for "all faculty meetings." During departmental meetings faculty engage in a variety of discussions. For example, during an observation visit, the English faculty used their meeting to collectively review a school-wide writing assessment. This did not involve teachers correcting papers independently. This meeting was a powerful hour which involved lively discussion related to student performance, the rubric that was used for assessment, and how this assessment of student performance would influence and shape instruction over the new weeks.

During "all faculty meetings" the entire faculty meets to engage in what feels like a town meeting. The principal is present at this meeting, and dialogue is open. All voices have the opportunity to be heard and faculty members appear to be very comfortable sharing where they agree as well as where they disagree on issues. During an observation visit, the "all faculty meeting" agenda was loaded with discussions which included ongoing exploration of the ways in which differentiated instruction can be utilized in classrooms, the importance of backwards planning and issues that were directly impacting the culture of the school. In particular, at this meeting, it was discussed the way in which students were using my space.com®. In fact, on the evening that this meeting was taking place, the Academy of the Pacific Rim was also sponsoring an information night with parents and families that would discuss how students were using the Internet and ways to help inform families and protect students.

Boston Prep and Excel Academy also greatly valued professional development, and while both schools were still in their early years of operation, both schools had made great efforts to operationalize professional development into the structure of their schools. Professional Development allows for members of a school to investigate, explore and evaluate existing practices that impact the culture of a school (Barth, 1990; Elmore, 2003; Fullan, 2001). At both of these schools there was structured time in the week for faculty to come together and meet to discuss issues.

Both Boston Prep and Excel Academy were participating in a charter school assessment project. Both these schools reported difficulty with the delay in receiving MCAS results and how this delay prevented using the results to directly impact curriculum and instruction in a timely fashion that would directly improve their students' performance. The assessment project involved a number of charter schools; the assessments were given every six weeks; and schools had student results within a few days. This was a collaborative effort to use data to drive curriculum and instruction and as a focus of professional development efforts. The faculty at Boston Prep and Excel Academy actively used these results to inform instruction and to chart the progress of their students.

At the Academy of the Pacific Rim, Boston Prep and Excel Academy, professional development was an organizational construct that fostered growth and development of both the leadership and members of the faculty through ongoing dialogue and reflection which was essential to the success of these professional development efforts. Professional development included everything from exploration and investigation into the best teaching practices to reflection and examination as to how the schools practices support and sustain the missions and values of each of these schools.

**CONCLUSION**

The leaders at each of these schools credited the strength of their purposely constructed systems as the foundation for their success. For example, Spencer Blasedale, Executive Director at the Academy of the Pacific Rim said that “we are continually and consistently reinforcing and improving rituals, rules and routines that create this culture of high achievement.” Scott McCue, Head of School at Boston Preparatory Public Charter School also reinforced the importance of structures and said “the key to our success is building structures which are consistent with our high expectations.” Yutaka Tamura, Executive Director at Excel Academy made the direct connection of effective leadership with systems and said “successful school leaders systematize expectations that align with the mission of the school, and this is how school culture is operationalized.” Creating systems and structures to support the schools’ cultures was an effective strategy utilized by the leadership at these three high-performing urban charter schools and in many ways was a signature of their success.

The data collected at The Academy of the Pacific Rim, Boston Preparatory Public Charter School and Excel Academy strongly suggested that structures and systems can be utilized to operationalize a culture that supports students’ academic performance. It also suggests that systems and structures can be established to support the five organizational constructs of leadership, curriculum and instruction, behavioral expectations, relationships and professional development. However, inherent in this finding is the need for clearly defined
expectations that support these structures and systems and for establishing consistency in implementing these systems. School leaders must closely examine the ways in which the structures and systems within their schools support the mission of their school. In addition, leaders must also think critically about the ways in which the mission of their school can be operationalized paying particular attention to identifying specific observable measures that will evidence these values and mission in action.

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An Examination of the Perceived Teaching Competencies of Novice Alternatively Licensed and Traditionally Licensed High School Science Teachers

Kathy Shea, Nipmuc Regional High, MA

ABSTRACT

There are two routes that novice high school science teachers can take to attain licensure, the traditional route (TLN) that includes an educational component and a student teaching practicum or the alternative route (ALN) for those who have taken few or no education courses. To assist these new teachers in becoming career professionals, most school have established mentoring programs. This study used an ex post facto survey research design to identify the perceptions of mentor teachers concerning the teaching competency of their assigned mentee. The results of this study did reveal a statistically significant difference in the perceptions of these mentors. The results of this study indicate that ALN teachers and TLN teachers may require different types of assistance from their assigned mentors. Recognizing the differing needs of teachers, school districts will need to develop mentoring programs.

Until the 1990s, becoming a science teacher traditionally involved attending a four-year Bachelor of Education program and completing a teaching practicum prior to entering the classroom. However, with the shortage of science teachers (Feiman-Nemser, Carver, Schwille, & Yusko, 1999; Hawley, 1992) and the move to increase the number of highly qualified teachers (Massachusetts Education Reform Act, 1993), there are now alternative routes to licensure for teachers. Traditional licensing routes include either undergraduate four- to five-year college or university programs or graduate education programs at a college or university. Both are considered traditional because they require teaching candidates to take education courses and a teaching practicum before entering a full-time teaching position. Alternative licensing routes bring novice teachers into the classroom after attending an abbreviated program or completing a district-based or university education program while teaching full-time. Novice teachers who are licensed without the traditional instruction in education and practicum are designated as alternatively licensed teachers (Darling-Hammond, 1992; Dillon, 2000; Feistritzer, 1999; Fensternacher, 1992; Hawley, 1992; Wake, 2001; Zeichner & Schulite, 2001). In most states, whether the candidate is following a traditional or alternative route to licensure, all novice teachers are required to pass a teacher proficiency test prior to entering the classroom.

Research has compared the pedagogical skills of traditionally and alternatively licensed teachers as they embark upon their teaching careers (Darling-Hammond, 1992; Dillon, 2000; Feistritzer, 1999; Fensternacher, 1992; Hawley, 1992; Wake, 2001; Zeichner & Schulite, 2001). Studies can be found that support, as well as, criticize alternative pathways. These studies identify the issues that novice teachers face as they begin their teaching careers.

Huberman (1989) suggests that all teachers progress through stages of development and that success during the first year may be critical in retaining teachers in the profession long term. Moir’s (1999) research has shown that as novice teachers enter the classroom, whether they are trained traditionally or alternatively, the stages they progress through include anticipation, survival, disillusionment, rejuvenation, and reflection. To aid novice teachers as they develop into professionals and to help them overcome obstacles that they encounter along the way, a number of school districts have developed induction programs. Induction programs vary from district to district, but a key component of most is mentoring (Feiman-Nemser, 1996; Luft, & Cox, 1998; Pan, Mitchler, Shapley, Bush, & Glover, 2000; Putz, 1992; Serpell & Bozeman, 1999). Mentoring is viewed as a powerful and effective tool to assist novice teachers as they develop and, in fact, is considered the most effective component of induction programs (Brooks, 1999; Coppenhafer & Schaper, 1999; Feinman-Nemser, 1996; Luft & Cox, 1998; Serpell & Bozeman, 1999; Villani, 2002).

To be successful, high school teachers are expected to know their content area, general pedagogy, and subject specific pedagogy, also known as pedagogical content knowledge (PCK) (Shulman, 1986). For science teachers, PCK (sometimes referred to as science-specific PCK) includes knowing and teaching the nature and processes of science, as well as, being able to use scientific equipment and instructional technology, running laboratories safely, and having knowledge of science curricular materials that are available for their classroom (Clermont, Borko, & Krajczik, 1994; Cochrane, DeRuiter, & King, 1993; Driver, Squires, Rushworth, & Wood-Robinson, 2001; Gess-Newsome, 1999; Hewson & Hewson, 1989; Mason, 1999; Mestre & Cokking, 2002; Patterson, Roehrig, Austin, & Luft, 2003; Shulman,
who have experienced a teaching practicum—mentoring parts provides advantages (CQ). Marshall and Grossman (1998) found that the traditional path produces success to mentor those novice teachers so that they may tailor their guidance appropriately.

Mentoring proves to be a valuable component for first-year teacher development, growth, and retention (Feinman-Nemser, 1996; Luft & Cox, 1998; Pan, et al., 2000; Putz, 1992; Serpell & Bozeman, 1999). Mentoring of first-year science teachers may determine the success of a novice science teacher’s long-term teaching career. The mentors assigned to first-year science teachers should be experts in their subject area, know general pedagogy, and understand pedagogical content knowledge as it applies to their subject and to science as a whole (Wojnowski, Bellamy, & Cooke, 2003). In addition, the mentor teacher should recognize that alternatively licensed science teachers bring to teaching a variety of life experiences obtained from previous careers (Long, 1998; Pan et al., 2000; Stoddart, 1992; Villani, 2002).

All the states that were examined for this study have some level of mentoring programs in place. Massachusetts, New Jersey, Connecticut (Connecticut Department of Education, 2004; Massachusetts Department of Education, 2005; New Jersey Department of Education, 2005) all have mandated mentoring programs in place. Rhode Island (Rhode Island Department of Education, 2005) and New Hampshire (New Hampshire Department of Education, 2005) have started mentoring initiatives in their school districts. Even though Maine does not require nor finance mentoring for all novice teachers, most Maine schools do have mentoring programs established (Hoff and Shinas, 2004). Because of this wide range of mentoring legislation and mentoring implementation, any relationship between an experienced teacher and a novice teacher could be classified as mentoring. However, certain characteristics should be recognized to classify a program as a legitimate mentoring program. These characteristics include training of the mentor, time allowed for the mentor to observe the novice teacher, regularly scheduled conferences between the mentor and novice teacher, and compensation for the mentor.

RESEARCH QUESTIONS

The debate over the appropriateness of traditional and alternative licensure routes to teaching has been well described in the literature (Darling-Hammond, Berry, & Thoreson, 2000; Grossman, 1989; Jelmborg, 1996; Miller, McKenna, & McKenna, 1998; Shen, 1986; Tamir, 1988; Veal & MaKinster, 2002). Additionally, science teachers’ PCK includes being able to organize and present the science material for understanding by all students with various learning styles. Novice high school science teachers who have received their licensure through an alternative pathway may know the material, but they may not know how to teach the subject so all students can succeed. Mentors assigned to novice high school science teachers may perceive deficiencies in content, general pedagogy and/or pedagogical content knowledge of their mentees and thus, play a crucial role in assisting these novice teachers with the development of the necessary skills and knowledge for teaching (Gess-Newsome & Lederman, 1999; Grossman & Richert, 1988; Monk & Dillon, 1995; Shulman, 1986; 1987; Tamir, 1988; Veal & MaKinster, 2002; Wojnowski, Bellamy, & Cooke, 2003).

PURPOSE OF THE STUDY

The purpose of this study was to examine the perceived teaching competency of traditionally and alternatively licensed novice high school science teachers, as interpreted by both mentor teachers and the novice teachers themselves.

Educators continue to debate the merits of both traditional and alternative programs available for licensure. The research results are equivocal. Miller, McKenna, and McKenna (1998) found that neither path produces differences in teaching performance or student success. Whereas, Hutton, Lutz, and Williamson’s (1990) results were inconclusive as to which novice teacher is better prepared for the classroom. Jelmborg (1996) found that the traditional path produces the better prepared teacher, whereas a number of studies indicate that the differences between traditionally licensed and alternatively licensed teachers disappear after a few months of teaching (Fenstermacher, 1992; Houston, Marshall & McDavid, 1993). Houston, Marshall, and McDavid (1993) stated any differences between teachers who are traditionally licensed versus those that are alternatively licensed could be explained by way of the practicum, which is part of only traditionally licensed teachers’ experience. A practicum, they contend, provides experience for the traditionally licensed teachers and allows them to progress beyond classroom management concerns that their alternatively licensed counterparts are still contending with. However, Hutton, Lutz, and Williamson (1990), reported that even for those who have experienced a teaching practicum, mentoring and collegial relationships are important success factors for all first-year novice teachers. Therefore, the distinction between traditional and alternative licensing may not need resolution, only awareness on behalf of mentors assigned to those novice teachers so that they may tailor their guidance appropriately.
The effect of mentoring on newly licensed or novice teachers indicates its importance on improving teaching practices and fostering teacher retention (Brighton, 1999; Eick, 2003; Ingersoll, 2003). However, studies that compare mentoring of traditionally licensed and alternatively licensed high school science teachers are few (Hudson, 2002).

It is during the first year in the classroom, (Halford, 1999; Houston, Marshall, & McDavid, 1993; Mager, 1992; Moir, 1999; Sandlin, Young, & Karge, 1993; Villani, 2002), that the traditionally licensed teachers and the alternatively licensed teachers exhibit major differences in their teaching practices. The emphasis of this investigation was on how the mentor interprets the teaching competency of the traditionally and alternatively licensed novice high school science teachers and how the novice teachers perceive their own teaching competency in that first year. The research was guided by two questions:

1) What perceptions do mentor teachers have of the science teaching competency of novice high school science teachers who have been traditionally licensed and of those who are pursuing an alternative route to licensure?

2) Are there differences in self-perception of teaching competency reported by novice high school science teachers who have been traditionally licensed and those who followed an alternative-licensing route?

**SAMPLE SIZE**

This study employed a non-experimental, survey research design. The subjects of this study were mentors of novice high school science teachers and novice high school science teachers who started teaching in September of 2004. All public high schools in the states of Massachusetts, New Jersey, Connecticut, Rhode Island, New Hampshire, and Maine, in total 890 schools, were contacted and asked to take part in this study. The actual number of mentors and mentees in those states was unknown since the study addressed only those questionnaires that were completed and returned through the mail. For this study 79 mentor questionnaires and 83 novice teachers’ questionnaires were returned and provided the data for analysis.

**INSTRUMENT**

Two forms of the instrument were used in this study. The first, distributed to mentors of first-year high school science teachers, was a questionnaire consisting of 73 questions divided into three sections. Section 1 had nine questions used to determine the characteristics of the mentor such as, courses taught, role in the school, and training received. Section 2 of the mentor questionnaire included eight questions used to determine the characteristics of the novice teacher being mentored. This section identified if the novice teacher received his/her license through a traditional or an alternative route.

Section 3 of the mentor questionnaire consisted of 56 questions to determine how the mentors perceived the level of teaching competency exhibited by the novice teacher being mentored. The 56 questions used a Likert Scale from SD (strongly disagree) to SA (strongly agree), with a final column to indicate ‘I don’t know’. The questions were presented in four sections. The first section had four questions that identified content knowledge. The second had 18 questions identifying general pedagogical skills of the mentee. The third had 28 questions that examined pedagogical content knowledge. The fourth and final section had six questions that addressed the professional growth of the novice teacher and how the mentor had assisted in this process. Once each question was developed, questions from the four areas were rearranged on the survey. Mangione (1995) indicates that in a mail survey the order of questions should not influence the responder because s/he can reread questions and go back to change answers. However, because this questionnaire was designed with multiple questions on certain concepts, mixing of the questions may have reduced random errors by the responder. Random errors, according to Mangione, indicate that the responder did not read completely and answer truthfully. By having multiple questions, the reliability of this instrument may have increased as random errors decreased.

The second form of the instrument was the questionnaire for the mentees. This questionnaire contained 68 questions, which were similar to those of the mentor questionnaire. The first seven questions identified the mentee’s educational background and licensure. The next five questions identified the mentor, the training the mentor received, and the relationship that existed between the mentor and mentee. The second part of the questionnaire consisted of 56 questions that were identical to the mentor questionnaire using the Likert Scale for the respondents, except that they were phrased in the first-person singular.
RESULTS

RESEARCH QUESTION 1

In order to answer research question one, the mean score for the responses to all the questions given by mentors of traditionally and alternatively licensed novice teachers were compared. Then each dimension, content knowledge, general pedagogy knowledge (GPK), pedagogical content knowledge (PCK), and professional growth was compared. The data indicated that there are, indeed, differences in mentor teachers’ perceptions of teaching competency of traditionally licensed novice (TLN) and alternatively licensed novice (ALN) high school science teachers. When evaluating three dimensions of teaching: general pedagogical knowledge, pedagogical content knowledge, and teacher professional growth, the data showed a difference in perception that was statistically significant between mentors of TLN teachers and mentors of ALN teachers. This difference indicated a perceived higher level of teaching competency for TLN high school science teachers than for ALN high school science teachers. However, for the dimension of content knowledge, the perceptions of mentors of TLN teachers and mentors of ALN teachers showed no difference. Table 1 outlines the dimension criteria and the mean value ratings assigned by mentor teachers.

Looking at the mean values displayed in Table 1, raises the question: Why are the perceptions of mentors of TLN and ALN high school science teachers different? In order to become an effective science teacher, the individual must have expertise not only in science, but must also possess GPK and PCK (Cochran, DeRuiter, & King, 1993; Darling-Hammond, 1992; Grossman & Richert, 1988; Hashweh, 1987). How novice teachers attain this knowledge base depends on the training they receive. TLN teachers have benefited from taking education courses designed to develop GPK and PCK and have tested their understanding and competency in a practicum environment. The novice teacher who has attained a license through an alternative route, however, may not have been exposed to the dimensions of teaching necessary for them to be effective in the classroom.

DIMENSIONS OF TEACHING

When the perceptions of competency in content knowledge of mentors of ALN teachers and mentors of TLN teachers were compared, no significant difference was found; this is somewhat surprising. It is often claimed that alternative route programs will bring individuals with more extensive content knowledge into the profession (Darling-Hammond, 1992; Dillon, 2000; Feistritzer, 1999; Fenstermacher, 1992; Hawley, 1992; Shen, 1997; Zeichner & Schulte, 2001). In this study, however, most novice teachers (both ALN teachers and TLN teachers) held a degree in science and many had worked in a science-related field before teaching. Therefore, it is likely that past experiences strengthened the science content knowledge of both groups.

The greatest difference in the perceptions of mentors of TLN and ALN high school science teachers was in the dimension of GPK. The survey questions relating to this dimension focused on classroom control, general teaching strategies, and daily classroom procedures. This finding supports Houston, Marshall, and McDavid’s (1993) research, which showed that the GPK of novice teachers who had participated in teacher education classes and student teaching (TLN) was stronger than that of alternatively licensed novice teachers. TLN teachers encounter and attend to general pedagogical issues while student teaching, whereas ALN teachers do not encounter these issues until they are faced with them in their first teaching situation. This difference may explain why mentors of ALN teachers reported lower competency than mentors of TLN teachers. By inference, ALN teachers may require more assistance than their TLN counterparts.

<table>
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<tr>
<th>Dimension</th>
<th>Mentoring Traditionally Licensed Novice Teachers</th>
<th>Mentoring Alternatively</th>
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<tr>
<td>Licensed Novice Teachers</td>
<td>Overall</td>
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<td></td>
<td>Content</td>
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<td></td>
<td>GPK</td>
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<td>PCK</td>
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<td>Professional Growth</td>
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<td>Mean</td>
<td>4.4</td>
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Table 1

Mean Values for Mentor Teachers

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PCK addresses how to teach science and includes knowing how to use science equipment properly (microscopes, Bunsen burners, vacuum pumps), while maintaining safety in the classroom. PCK also incorporates understanding how students learn science, where misconceptions arise, and how to best address them. Teachers with a command of PCK will know how to use inquiry investigations, analogies, illustrations, examples, and demonstrations. Furthermore, teachers should know state and national standards as well as how to maintain an overall enthusiasm for teaching science literacy to all students (Cochran, DeRuiter & King 1993; Driver, Squires, Rushworth & Wood-Robinson, 1994; Gess-Newsome & Lederman, 1999; Grossman & Richert 1988; Morine-Dershimer & Kent, 1999; Shulman, 1986; 1987; Tamir, 1988; Veal & MaKinster, 2002).

In this study, there were differences in perceptions of PCK competency between mentors of TLN high school science teachers and mentors of ALN high school science teachers. Mentors of TLN teachers reported higher competency in PCK than did mentors of ALN teachers. One reason for the differences in mentor teachers' perceptions may be attributed to the ALN high school science teachers' lack of a teaching practicum. This supports the research conducted by Cochran, DeRuiter, and King (1993) and Darling-Hammond (1992) who stated that teachers who do not participate in teaching practicums would have less developed PCK. Feiman-Nemser (1996) claims that some mentor teachers are unable to identify and report best teaching practices. Although further research is needed to support or refute this contention, the present study does suggest that differences in PCK competency existed and were recognized by mentors.

The professional growth dimension was included as part of the mentors’ evaluation of mentees’ competency. This information was gathered from questions which asked how TLN and ALN teachers responded to suggestions from their mentors and if the novice teachers accepted and incorporated those suggestions into their own teaching practices. Connelly (2001) suggests that by removing the perceived threat of evaluation by the mentor teacher, trust is built between the novice teacher and the mentor teacher. As this questionnaire revealed, most mentors did not evaluate their novice teachers. The relationship between the mentor and novice teacher was collegial and friendly. With a degree of trust in place, mentor teachers and novice teachers are then able to communicate effectively. Mentor teachers should be able to identify if their novice teachers are accepting of new ideas, if they are willing to modify their teaching, and if they are able to reflect on their teaching practices. The results of this study indicate that mentor teachers of TLN high school science teachers perceive a greater ability of their mentees to accept ideas and reflect on their teaching than mentors of ALN teachers. This study supports Houston, Marshall, and McDavid's (1993) research that found that ALN teachers were concerned with generic or basic teaching issues whereas TLN teachers were more concerned with in-depth or complex teaching issues that were similar to those issues being dealt with by the more experienced teachers.

RESEARCH QUESTION 2

Traditionally and alternatively licensed novice high school science teachers who responded to this questionnaire showed no differences in their perceptions of teaching competency overall, nor differences in any of the teaching dimension (see Table 2).

These results signify that all novice teachers perceived themselves to have a high level of teaching competency for every dimension of teaching that was under investigation. When each mean was compared, no statistical difference was identified between the TLN teachers and ALN teachers' self-perception of their competency. The time of year when the questionnaire was administered may, in part, account for this finding. Novice teachers were at the end of their first year of teaching and, having succeeded in completing the year, may have answered the questions with a confidence they might not have possessed had the questionnaire

<table>
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<td>Mean Values for Novice Teachers</td>
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<td><strong>Dimension</strong></td>
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been administered at the end of their first semester. Mentor teachers, however, who did perceive differences in teaching competency may have answered the questions using their perspective of the whole year, reporting on the teaching ability of their mentee based on a year of teaching.

Another explanation for the lack of perceived differences in teaching competency may be that only successful novice teachers, those who were told by their department chair or administration that they were retaining their job, answered the questionnaire. Once again, this would suggest that the novice teachers answered the questions when they felt successful, resulting in an over-estimation of their classroom competency.

It is also possible that ALN teachers over-estimated their classroom abilities while TLN teachers under-estimated them. TLN teachers are more likely to recognize areas of their practice that need improvement (Houston, Marshall & McDavid, 1993) because of their training and understanding of pedagogy and teaching complexities. ALN teachers, on the other-hand, may be satisfied with a performance that is less than optimal. Sandlin, Young, and Karge’s (1993) study supports this contention as they found that TLN teachers had a higher level of concern about their teaching ability than did ALN teachers.

**IMPLICATIONS FOR PRACTICE**

**IMPLICATIONS FOR MENTOR TRAINING**

A mentor teacher’s role may be crucial in helping the alternatively licensed teacher develop the required knowledge and skills during the first years of teaching. A number of studies have been conducted that support this idea especially when it pertains to the acquisition of PCK (Grossman & Richert, 1988; Houston, Marshall, and McDavid, 1993; Hutton, Lutz, and Williamson, 1990; Luft, 2003; Monk & Dillon, 1995; Wojnowski, Bellamy, & Cooke, 2003).

It is widely accepted that all new teachers benefit from having the guidance and assistance of a mentor teacher when they enter the classroom and many states mandate that a mentor be assigned to a novice teacher (Feiman-Nemser, Carver, Schwille & Yusko, 1999; Mager, 1992; Putz, 1992; Wood, 1999). Though the requirements for mentoring vary from district to district, most agree that mentors should be trained for the role (Brooks, 1999; Coppenhaver & Schaper, 1999; Feinman-Nemser, 1996; Luft & Cox, 1998; Serpell & Bozeman, 1999; Villani, 2002). The perception that the mentor teachers in this study held with respect to the competency of their novice teachers has notable impact on the type of training that mentor teachers may need in order to be successful in their role.

Although the results showed significant differences between the mentor teachers’ perceptions of the competency of those novice teachers who are traditionally licensed and those who are following an alternative licensing route, a concern about participant bias must be addressed. The mentor teachers knew that they were involved in a survey that was looking at the skills of traditionally and alternatively licensed teachers and their responses may have been influenced by this knowledge. Responses that are biased because of anticipating what is being studied or giving answers that are designed to please the researcher are known as exhibiting the Hawthorn Effect (Ross, 1999). However, no mentors in this study supervised both TLN teachers and ALN teachers and were not comparing mentees, giving the researcher greater confidence that the data presented are representative of real differences in performance.

As this study identified differences in perceptions of mentors of TLN high school science teachers and mentors of ALN high school science teachers with respect to teaching competency, the implication is that mentors may need specific training to more appropriately assist new teachers. Mentor teachers of ALN teachers need to be aware that their mentee will not have the basic GPK and PCK needed to plan lessons, assess learning, or manage a classroom. Furthermore, ALN teachers may be unable to easily translate the mentor’s advice into practice. As they begin their teaching career, ALN teachers may not share the same education-specific vocabulary as their mentor. The differences in professional growth perceived by the mentors may be due to the ability of TLN teachers to recognize advice that is similar to the learning in their previous pedagogical coursework and to be able to act on it and the inability of ALN teachers to really understand what is being suggested. It, therefore, becomes imperative for mentors of ALN high school science teachers to clarify terminology and model best practices for the mentee whenever possible.

The state of New Jersey has already recognized the need for differences in the mentoring of TLN and ALN teachers and requires more mentoring for novice teachers who are pursuing alternative licensure while they are teaching (New Jersey City University, 2005).
IMPLICATIONS FOR TEACHER PREPARATION

This study indicates that the knowledge and skills developed by traditionally licensed novice teachers during their teacher preparation program is critical to developing competency in the classroom. It must be noted that 14 out of the 35 ALN teachers in this study had taken some education courses, but none had participated in a practicum. Therefore, the lack of a supervised practicum may be essential to the development of classroom competency. Practica are supervised by classroom teachers and college supervisors. This study suggests that mentors may need to learn more about the role played by college supervisors in advising novice teachers and how to assume this role themselves when working with novices with no prior classroom experience. ALN teachers need to advance beyond the daily issues of teaching towards a deeper understanding of how students learn and reflective practice. In order for mentors to assist them in this growth, mentor education, which involves shadowing or working with college or university faculty, may be warranted.

LIMITATIONS OF THE STUDY

This study examined mentors’ and mentees’ (novice high school science teachers) perceptions of teaching competency. The method used in this study, mailing a questionnaire to all public high schools in the states of Massachusetts, New Jersey, Connecticut, Rhode Island, New Hampshire, and Maine was limited by response rate and the design of the questions. The data used were self-reported. Self-reporting can result in bias caused by lack of guidance or supervision when respondents answer the questions. A second bias is self-selection. This occurs when only people who want to respond to the survey respond. Because this questionnaire was mailed to schools, the motivation to participate is based on the decision of the individual teacher, therefore, teachers who are interested in mentoring and routes to licensure may have been the only ones to answer the questionnaire (Sporer, 2001). In addition, mentor bias (favoring one type of mentee over the other) could also have compromised the results.

The relationship between the mentor and novice teacher may also have affected these results. Smith (2003) identified the mentor/mentee relationship as important for mentoring success; this same relationship may also be important for accurate reporting in this study. Question 16 on the mentor survey and questions eight and nine on the mentee survey were included to help identify the overall relationship that exists between the respondents. This study found that the relationship between the mentor and novice teacher was collegial or friendly. The assumption was that the mentor identified how the novice teacher was teaching and accurately reported it. However, if this relationship was amiable and was inaccurately reported or if the mentor was not familiar with the teaching practices of his/her novice teacher, then the results may be inaccurate. In addition, the mentors in this study may have differences in their understanding of teaching competency, leading to discrepancies in the way they respond to the questions.

Another concern for this study involves the validity of identifying who is a TLN teacher and who is an ALN teacher. The following two questions were used in this study: (1) Did the novice teacher participate in education classes? and (2) Did s/he participate in student teaching? A negative answer to the second question designated the respondent as an ALN teacher, but if the respondent indicated a positive response to the second question then s/he was designated as a TLN teacher. However, this study did not identify those novice teachers who might have participated in condensed teacher training programs with a teaching practicum component. Programs such as Massachusetts Institute for New Teachers (MINT) in Massachusetts and Beginning Educator Support and Training Program (BEST) in Connecticut have a teaching practicum that occurs during the summer. A person who had participated in a condensed program may or may not have indicated that s/he had participated in a student teaching practicum. The questionnaire did not ask whether the respondent had worked in a classroom as a substitute teacher prior to their first year of teaching. Previous teaching experience may have affected their classroom competency and hence the perceptions reported by both mentors and mentees.

The questionnaires were mailed at the end of the school year; this factor may also have influenced the results. By having a year’s experience, the competency of the novice teachers in the classroom may have increased. If this questionnaire had been administered at the end of the first semester, the results may have been very different.

RECOMMENDATIONS AND FUTURE RESEARCH

This study recommends that individuals interested in pursuing a teaching career take advantage of educational programs by participating in educational classes and a teaching practicum in order to develop a better understanding of GPK and PCK. By starting with knowledge of how to teach science, novice teachers may
demonstrate greater competency in the classroom. In light of the nationwide science teacher shortages, however, alternative programs are likely to persist. Therefore, mentoring programs in schools should be evaluated to determine if the needs of novice teachers are being met. This evaluation is important because mentors reported that TLN high school science teachers and ALN high school science teachers have different levels of teaching competencies and, therefore, mentors need to understand how to assist novice teachers of varying ability. The involvement of a university or college in a school’s mentoring program could help school staff to better identify teaching competencies categorized within GPK or PCK. Such involvement may also assist mentors in providing the guidance necessary to improve their novice teachers’ practices.

This study has shown that there are differences between mentor teachers of TLN and ALN high school science teachers’ perceptions of teaching ability of novice teachers, which reflects which route to licensure was pursued. To determine if mentors perceive a difference in teaching competency of novice high school science teachers at the beginning of the school year, this questionnaire would need to be administered during the first term of the year. In addition, this survey could also be used to examine middle school teachers’ perceived teaching competency.

Because alternative programs to certification are an established part of teacher recruitment, research that examines how alternative certification can best prepare highly competent teachers is needed. The following is a list of questions that need further exploration:

**What skills do mentors need to assist mentees?**

Research is needed to examine whether mentors are able to identify the strengths and weaknesses of their mentees’ teaching. Mentor teachers need to assist their mentee not only with the basics of classroom and behavior management, but also with the intricacies of lesson planning and assessment, as well as how to evaluate their own teaching and their students’ learning. Research into the most effective ways for mentors to convey this information to novice teachers is called for.

**How do mentors gain the skills necessary to assist mentees successfully?**

Mentor training should be researched to determine how to best assist mentors to learn what they need to support the mentees in their schools. Most mentors in this study participated in a summer training session; this may not be sufficient. Research is needed to establish what information is important for mentors to learn and what period of time is needed for mentors to efficiently learn it.

**What are the compelling needs of novice teachers and are mentor teachers meeting these needs?**

Research is needed to discover the critical components found in college and university practica, as well as those found in truncated alternative programs that assist novice teachers in the development of teaching competency. These components can then be incorporated into all mentoring programs. Finally, a study of comprehensive evaluation of mentoring programs should be undertaken to determine if the needs of novice teachers are being met.

**SUMMARY**

The results of this study indicate that there are differences in mentor teachers’ perceptions of the teaching competency of novice teachers, and this was related to the route taken to licensure. The TLN high school science teachers were perceived as demonstrating greater competency than ALN high school science teachers in overall teaching performance and in three of four teaching dimensions examined. This information provides a basis for suggesting specialized mentor training for those working with ALN teachers. Moreover, the results of the study indicate that as ALN teachers lack some of the necessary general and science-specific pedagogical knowledge when they enter the classroom, their participation in some form of teacher-training program may be essential.

The National Education Association (NEA) (2001) states that the process of choosing mentors should be based on the mentor teacher’s knowledge of school, community, and teaching practices. The NEA also advises that mentor training should be a year-long process not a one-shot program, because only an ongoing process is effective for training mentors. Both of these recommendations put forth by NEA may be important to current mentoring programs; however, this study indicates that training of mentor teachers should also acknowledge the different needs of ALN and TLN teachers.

This study indicated that TLN and ALN high school science teachers’ perceptions of their teaching competency were similar. It has been suggested that ALN teachers may fail to recognize the complexities of teaching and therefore rate their performance more highly than TLN teachers do. Extensive observation of classroom practices is needed to examine this contention.
The study has contributed to the body of teacher education knowledge by identifying potential areas of concern for all mentor teachers. Although alternative routes to licensure are essential in these times of teacher shortages, this study suggests that ALN high school science teachers will need a different form of mentoring to that of TLN high school science teachers if they are to acquire the necessary teaching skills.

REFERENCES


A Pilot Study Exploring the Relationship Between Teachers’ Mathematics History Knowledge and Images of Mathematics

Danielle M. Goodwin, CompassLearning, a division of Weekly Reader

ABSTRACT

This pilot study explored the relationship between the images of mathematics and mathematics history knowledge held by high school teachers. What teachers believe about the nature of mathematics affects the way they teach mathematics. It is theorized that studying the history of mathematics allows teachers to form a wide view of the nature of mathematics and positively transforms their teaching practices. To explore these questions, a non-experimental, survey research design was employed. This paper presents the preliminary results from the first 56 pilot study responses received.

The purpose of the study was to explore the relationship between the images of mathematics and mathematics history knowledge held by high school teachers. Sam and Ernest (1998) utilized the term images, defining it as a collection of attitudes and beliefs about the nature of mathematics, mathematical ability and mathematics education.

It is widely acknowledged that teachers enter the profession lacking both mathematical competency and an adequate understanding of the nature of mathematics (Ball, 1990). Thompson (1992) asserts that very few teachers have an informed perspective about the nature of mathematics, even those with an undergraduate degree in mathematics.

What teachers believe about the nature and role of mathematics affects the development of mathematics curricula in schools, as well as the way mathematics is taught (Dossey, 1992; Lerman, 1986; Thompson, 1992). Based on their personal experiences, teachers create and hold beliefs about the subjects they teach (Clark, 1988). Barbin (1996) proposes that studying the history of mathematics allows teachers to form a wide view of the nature of mathematics and positively transforms their teaching practices. Further, mathematics teachers need to learn the history of mathematics, because that history is a part of mathematics itself (Kline, 1980). Shulman (1987) contends that through study of the history and philosophy of a discipline, teachers can come to understand its structure. In particular, if teachers are to be successful in conveying the power and beauty of mathematics, they themselves need to know the “whys” as well as the “hows” (NCTM, 2000). Further, as Bishop (1988) argues, mathematics teachers need to know the history of their subject because their teaching contributes to the development of mathematics in general by developing the mathematicians of the future.

RESEARCH QUESTIONS

Studying high school teachers’ images of mathematics, their mathematics history knowledge and the connections between images and history knowledge is very worthwhile. The research questions that guided this study are:

1. What images do high school teachers have of mathematics?
2. What do high school teachers know about the history of mathematics?
3. What is the relationship between high school teachers’ mathematics history knowledge and their images of mathematics?

To quantitatively explore these questions, a non-experimental, survey research design was employed. The chosen survey method was a questionnaire distributed to approximately 900 public high school mathematics teachers in California. In this paper, results from the first 56 surveys received (the pilot study) will be discussed.

No mathematics history test relevant to teachers was found through an exhaustive literature search. The researcher therefore developed an instrument that combines questions from many surveys about mathematics to form a survey designed to reveal teachers’ images of math and also their historical knowledge of mathematics. The first 18 items of the instrument form the Mathematical Images Survey. A panel of three experts (each with an advanced degree in Mathematics Education and extensive knowledge of mathematics history) was involved in creating the Mathematics History Test (items #19 to #34 of the instrument) that contains mathematics history items relevant to K-12 instruction. Demographic items were surveyed using eight items at the end of the combined survey instrument.
DEMOGRAFICS OF THE PILOT STUDY RESPONDENTS

In this pilot study, 56 surveys were completed by anonymous California high school mathematics teachers from randomly chosen California public high schools. A frequency analysis of the demographic items revealed that approximately 54% of the respondents have been teaching high school mathematics for 12 or more years. This first, limited sample of the population of California high school teachers may not be representative. It is possible that because three copies of the survey were mailed to each randomly chosen school in care of the department chair, the department chairs (who presumably have more teaching experience) have responded first. A frequency analysis of the demographic items is presented in Table 1.

OVERALL IMAGE OF MATHEMATICS

Item #11 (see Table 2) was included on the survey for a gross measure of the overall image of mathematics. Item #11 was answered in a valid way by approximately 98% of respondents. Table 2 shows a frequency analysis of item #11.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Years Teaching High School Mathematics</td>
<td></td>
</tr>
<tr>
<td>0 – 3 years</td>
<td>21.4</td>
</tr>
<tr>
<td>4 – 7 years</td>
<td>16.1</td>
</tr>
<tr>
<td>8 – 11 years</td>
<td>8.9</td>
</tr>
<tr>
<td>12 or more years</td>
<td>53.6</td>
</tr>
<tr>
<td>Highest Degree Completed*</td>
<td></td>
</tr>
<tr>
<td>Bachelor</td>
<td>27.3</td>
</tr>
<tr>
<td>Master</td>
<td>69.1</td>
</tr>
<tr>
<td>Doctorate</td>
<td>3.6</td>
</tr>
<tr>
<td>Number of History Classes Taken</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>46.4</td>
</tr>
<tr>
<td>1</td>
<td>48.2</td>
</tr>
<tr>
<td>More Than 1</td>
<td>5.4</td>
</tr>
<tr>
<td>Read History Outside of Professional Development</td>
<td></td>
</tr>
<tr>
<td>Never</td>
<td>32.1</td>
</tr>
<tr>
<td>Sometimes</td>
<td>57.1</td>
</tr>
<tr>
<td>Frequently</td>
<td>10.7</td>
</tr>
</tbody>
</table>

* indicates that one respondent chose not to respond to this demographic item and the percentages shown for this characteristic are the “valid” percentages.

Table 2

Frequencies of Responses to Item #11 (N=55)

<table>
<thead>
<tr>
<th>Mathematics is…</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Creating and studying abstract structures, objects…</td>
<td>9.1</td>
</tr>
<tr>
<td>Logic, rigor, accuracy, reasoning and problem-solving</td>
<td>21.8</td>
</tr>
<tr>
<td>A language, a set of notations and symbols</td>
<td>3.6</td>
</tr>
<tr>
<td>Inductive thinking, exploration, observation, …</td>
<td>25.5</td>
</tr>
<tr>
<td>An art, a creative activity, the product of the…</td>
<td>3.6</td>
</tr>
<tr>
<td>A science; the mother, the queen, the core, a tool…</td>
<td>23.6</td>
</tr>
<tr>
<td>A tool for use in everyday life</td>
<td>12.7</td>
</tr>
</tbody>
</table>

ITEM DESCRIPTIVES

Items #2 to #10 and #12 to #18 (see Table 3) formed the Likert-Type images of mathematics questions. The answer format for those questions was a Likert-Type scale with a score of 1 corresponding to “Strongly Disagree,” 2 corresponding to “Disagree,” 3 corresponding to “Slightly Disagree,” 4 corresponding to “Slightly Agree,” 5 corresponding to “Agree,” and 6 corresponding to “Strongly Agree.” Item #10 (Mathematics makes a unique contribution to human knowledge) exhibited a very small amount of variation (SD = .486). All 56 respondents agreed with item #10 (with responses only ranging from Slightly Agree to Strongly Agree), with 75% of respondents reporting that they strongly agreed with the item. Table 3 shows the mean and standard deviation for the image construct items (a score of 1 corresponds to Strongly Disagree and a mean of 6 corresponds to Strongly Agree).

CONSTRUCT RELIABILITIES AND DESCRIPTIVES

As for the five image constructs, the factor analysis shows at this time that the items from the “Alive & Ongoing” and “Takes Twists & Turns” load together (and will henceforth be referred to as “Ongoing and Takes Twists & Turns” in this paper). The merged construct formed from using all of the items from those two constructs (with the exception of item #16 which did not load highly on this merged construct and was therefore not included in the scale) has a Cronbach alpha reliability of .61. Factor analysis also showed that the items from the two image constructs “For Everyone” and “Connected” also load together (in this paper, this
merged construct will be henceforth referred to as “For Everyone and Connected”). Again, taking the items from these constructs (all items but #6 and #7 which do not load highly on the merged construct), a sufficiently high reliability of .68 is shown. In this pilot study, the items from the construct “A Human Process” did not load together during a factor analysis, nor did they provide a Cronbach alpha reliability of at least .60. For this pilot study, items that did not load strongly on one of the two merged constructs will not be considered.

The merged construct “Ongoing and Takes Twists & Turns” is created from items #5*, #14, #15, #8, #9* and #18 (see Table 3). Items with an asterisk (*) were worded in a negative direction on the survey instrument and are recoded when forming the construct so that a score of 6 corresponds to “Strongly Disagree,” 5 corresponds to “Disagree,” 4 corresponds to “Slightly Disagree,” 3 corresponds to “Slightly Agree,” 2 corresponds to “Agree,” and 1 corresponds to “Strongly Agree.” In the same way, the merged construct “For Everyone and Connected” is created using items #2, #3, #4* and #17*. The mean and standard deviation for the merged constructs are shown in Table 4.

The mean score of both merged constructs is roughly 5, which corresponds to “Agree” on these Likert-Type items. Kolmogorov-Smirnov normality testing shows that neither merged construct score is roughly normally distributed in this sample. So, in order to analyze this data, the scores will be clustered into groups. The median score of the “Ongoing and Takes Twists & Turns” merged construct is 5.17 and the median score of the “For Everyone and Connected” merged construct is 5.5.

<table>
<thead>
<tr>
<th>Table 3</th>
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<tbody>
<tr>
<td>Means and Standard Deviations for Images of Mathematics Items Categorized by Construct</td>
</tr>
<tr>
<td>Construct</td>
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<tr>
<td>----------</td>
</tr>
<tr>
<td><strong>A Human Process</strong></td>
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<td></td>
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<td><strong>For Everyone</strong></td>
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<td></td>
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<tr>
<td><strong>Alive &amp; Ongoing</strong></td>
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<td></td>
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<tr>
<td><strong>Connected</strong></td>
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<td></td>
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<tr>
<td></td>
</tr>
<tr>
<td><strong>Takes Twists &amp; Turns</strong></td>
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</table>

<table>
<thead>
<tr>
<th>Table 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Means and Standard Deviations for Merged Images Constructs</td>
</tr>
<tr>
<td>Merged Construct</td>
</tr>
<tr>
<td>------------------</td>
</tr>
<tr>
<td>Ongoing and Takes Twists &amp; Turns</td>
</tr>
<tr>
<td>For Everyone and Connected</td>
</tr>
</tbody>
</table>
Two groups will be formed for each merged construct: 1) scores at or above the median and 2) scores below the median.

**HISTORY TEST RELIABILITY AND DESCRIPTIVES**

The Mathematics History Test portion of the survey instrument, containing 16 items, had a Kuder-Richardson reliability of .72. The mean of this sample was approximately 10.2 out of 16 items correct with a standard deviation of roughly 3.4. Kolmogorov-Smirnov normality testing also shows that the Mathematics History Test total number of correct items score is roughly normally distributed in this sample.

To further test the validity of the mathematics history test, an ANOVA analysis was performed to determine if respondents who reported reading mathematics history books outside of professional development or had taken one or more mathematics history class would have significantly different mean scores on the mathematics history test. ANOVA analysis (F = 8.3, p = .001) and post hoc testing revealed that there was a significant difference in mean mathematics history score between those who never read mathematics history books outside of professional development and those who sometimes or frequently read mathematics history books outside of professional development. No significant differences in mean history score were found between respondents reporting taking no mathematics history classes and those responding that they took one or more history classes.

**EXPLORING THE RELATIONSHIP BETWEEN HISTORY TEST SCORE AND IMAGES**

**Demographics versus History Score**

Respondents with a Master’s level degree had a mean score of 10.9 on the mathematics history test (with a standard deviation of 0.55). t-testing reveals this to be significantly different than respondents with only a Bachelor’s level degree (mean score of 8.3 with standard deviation of 0.80). Testing revealed no significant difference in mean history test score between teachers who reported teaching for 0-3, 4-7, 8-11 or 12 or more complete years of high school mathematics.

**Overall Image of Mathematics versus History Score**

Many respondents chose to respond to Item #11 (see Table 2) with Mathematics is “logic, rigor, accuracy, reasoning and problem-solving,” “inductive thinking, exploration, observation, generalization” or “a science; the mother, the queen, the core, a tool of other sciences.” Accordingly, all other responses were grouped into an “other” category. ANOVA testing revealed that no significant difference in mean history scores between the groups was found.

**MERGED IMAGE CONSTRUCTS versus HISTORY SCORE**

T-testing revealed no significant differences in mean mathematics history score between those who were at or above the median score on the merged construct “Ongoing and Takes Twists & Turns” and those below the median score. t-testing also revealed no significant difference in mean mathematics history score between those who were at or above the median score on the merged construct “For Everyone and Connected” and those below the median score.

**LIMITATIONS AND FUTURE WORK**

In this pilot study, many respondents reported teaching for 12 or more years. Therefore, this first pilot study sample may not be representative of the general population of California high school teachers. Also, with such a small sample size, many statistical tests were inappropriate. Moving forward, because the reliabilities on the various pieces of the survey instrument are sufficient, this researcher is looking forward to continuing this line of research with the full, larger scale study in order to more fully explore the relationships between mathematics history knowledge and images of mathematics held by high school mathematics teachers.

**References**


Can Our Conception of the Nature of Science Be Tentative Without Qualification?
Rocco J. Perla, Mount Wachusett Community College

ABSTRACT
The tentative and revisionary character of scientific knowledge is believed to play a central role in nature of science (NOS) studies by teachers, researchers, and curriculum developers. However, some educational researchers and scholars have recently expressed serious concerns about the view of tentativeness and change espoused in the science education literature claiming that it is simplistic, one-dimensional, inconsistent, irresponsibly vague and self-contradictory. Despite these concerns, there are few detailed examples of how these types of problems manifest themselves in the science education literature and the difficulties they might pose for learners and other researchers. Accordingly, this article isolates and critically examines a single foundational proposition about the tentativeness of science made by leading NOS researchers. Specifically, this paper examines the assertion by Lederman, Abd-El-Khalick, Bell & Schwartz (2002) that “…similar to scientific knowledge, conceptions of NOS are tentative and dynamic” (p. 499). It is demonstrated that this generalization has some important inconsistencies and limitations that are problematic at the philosophical and instructional level. Throughout the article, it is argued that a logic-linguistic analysis of epistemic propositions made by researchers is desirable in NOS studies and that seemingly benign propositions can give rise to different viable, yet diametrically opposed, interpretive frameworks.

In a paper presented at the 2001 international meeting of the Association for the Education of Teachers in Science (AETS), Abd-El-Khalick, Lederman, Bell and Schwartz discuss issues related to the development and refinement of the View of Nature of Science Questionnaire (VNOS)—an instrument aimed at validly and meaningfully assessing learners’ conceptions of the nature of science. This AETS conference paper was later published in the Journal of Research in Science Teaching (Lederman, Abd-El-Khalick, Bell & Schwartz, 2002), and the VNOS is a frequently used instrument by science education researchers presently.

In the process of justifying the VNOS and providing contextualizing text for this instrument, Lederman et al. (2002) make three very important points that relate to the nature of science (NOS). First, they clearly point out that there is an important difference between the nature of science (e.g., epistemological issues, values and assumptions) and the processes of science (e.g., observing, hypothesizing and experimenting)—and that the two are often conflated. Second, they effectively argue that the tentative and revisionary character of science plays a central role in nature of science studies. Third, they argue that there is a general consensus among science educators, philosophers, historians and sociologists of science related to key NOS concepts. Each of these three points is reasonable and well substantiated in the current science education literature and go unchallenged here.

What is challenged, however, is the logic and praxis of the authors’ contention that “…similar to scientific knowledge, conceptions of NOS are tentative and dynamic” (Lederman et al., 2002, p. 499). In a prior publication that reviews attempts at improving science teachers’ conception of the nature of science, Abd-El-Khalick & Lederman (2000) express a similar thought and viewpoint:

…a review of the research literature on NOS needs to be undertaken and ‘read’ from the standpoint that, much like scientific knowledge, conceptions of NOS are necessarily tentative and historical. (p. 668)

What the authors mean to convey by these statements, it would seem and appear, is the view that conceptions of the nature of science have shifted over time, mirroring shifts in the philosophy, history and sociology of science (e.g., the “Pre-Kuhn” versus the “Post-Kuhn” Era), and that these shifts have had an impact on how the science education community has defined NOS over the past century.

On the surface, it is hard to find fault with the idea that conceptions of NOS are tentative and dynamic. However, when analyzed in a systematic manner, there are key and highly significant problems or at least important limitations with the view that “similar to scientific knowledge, conceptions of NOS are tentative and dynamic.” More specifically, the problem lies with stating that the larger more global epistemic conception and framework of NOS is tentative and then applying this generalization to each of the tenets of NOS without important qualifications and exceptions (such as addressing the different degrees and meanings of tentativeness as they relate to each tenet). These (sub-level) tenets, principles or concepts that define and exemplify NOS presently are outlined by Lederman et al. (2002) and are reinforced in the National Science Education Standards (National Research Council [NRC], 1996) and
the science education literature in general. These tenets include but are not limited to the following five claims:

1. Science is empirical
2. Science is a human enterprise
3. Science involves creativity and human imagination
4. Scientific knowledge is subjective and theory laden
5. Scientific knowledge is stable yet tentative

It should be mentioned that each of these five tenets are largely consistent with and define the Post-Kuhn Era and view of NOS, and that science educators have identified the tentative nature of science as the central NOS tenet over the past decade (see Perla, 2006).

The contention that our general conception of NOS is itself tentative is inconsistent and fraught with difficulties when applied to the five tenets above, and especially when applied to the tentativeness of scientific knowledge (tenet #5), and requires some clarification and discussion. This article demonstrates how the view that our conception of NOS is tentative is (1) problematic and opens the door to some strange philosophical and instructional implications, and (2) suggests a confusion between individual NOS tenets and the more comprehensive and general NOS framework that subsumes these tenets. Moreover, part of the importance of this particular assertion by Lederman et al. (2002) is that it is a *meta-epistemological* assertion, or an assertion that attempts to subsume and organize individual epistemic claims, such as the five tenets above. This fact alone makes this assertion worthy of intense scrutiny in order to gauge its limitations, validity and generalizability.

What follows is a brief critical analysis of the contention by Lederman et al. (2002) that “similar to scientific knowledge, conceptions of NOS are tentative and dynamic” (p. 499) and an exploration into the logical and instructional consequences and implications of this statement. Some may argue that the point of this article is trivial and “hair-splitting” over terminology, and that it throws the baby out with the bath water, or that the gist of this statement is easily discernable without diving into a logico-linguistic analysis. However, it should be stressed that (1) the human language is extremely vague, subtle, imprecise, often amorphous and packed with hidden meaning (especially epistemic terms and concepts) (Thagard & Beam, 2004), (2) the science education literature has clearly demonstrated that students (K-16) have difficulty understanding epistemic and NOS-related terms and concepts such as proof (Lederman & OMalley, 1990) and tentativeness (Johnson & Southerland, 2001), and (3) teaching NOS in the K-12 setting and beyond is an extremely difficult endeavor (Olson & Clough, 2003). Because NOS concepts are fundamentally epistemic concepts (Lederman, 1992), they are and should be subject to the linguistically-semantic (propositional) scrutiny that defines the field of epistemology and its attempt to clarify the meanings of words and sentences in the analytic tradition and spirit of Russell and Wittgenstein. In fact, the method of analysis used in this article is in many ways an attempt to apply Wittgenstein’s (1922, 1963) view of philosophy—as an elucidatory versus descriptive practice that aims at the logical clarification of thought and language—to the science education literature and specifically NOS studies and propositions. Indeed, this article focuses more on the context of justification than the context of discovery (see Reichenbach, 1938), as the former context (in its pure form) has never really taken hold in educational research and analyses, particularly in the “post-Kuhn” and postmodern era.

Moreover, the issue of conceptual clarity and logical coherence addressed in this article through the analysis of a single (and to some degree contradictory) statement about tentativeness may be no more different from the types of questions, thoughts and confusions of students that may or may not become explicit and discussed by the student or teacher in the classroom. Inaccurate, incomplete, trivial and illogical interpretations of tentativeness in science—on the teacher or student’s part—is surely subversive to the goal of scientific literacy and a deeper appreciation of the scientific enterprise. As Johnston and Southerland (2001) argue in their study of the multiple meanings of tentative science among college learners, “…students’ use of a specific meaning of ‘tentative’ is dependent upon their underlying epistemological standards for science” (p. 1), and that “…an apparently slight [italics added] misinterpretation of science’s tentativeness on the part of a student may be indicative of a more fundamental misunderstanding regarding science as a way of knowing” (p.1).

Slight misinterpretations of science’s tentativeness are bad enough instructionally, but are only exacerbated when we consider that the foundational proposition of NOS studies—that science is stable yet tentative—is flawed logically. Douglas Allchin (2004) is one of a handful of people to recognize this problem when he states “The phrase ‘science is tentative but durable’ is irresponsibly vague, if not self-contradictory. Science educators therefore need to adopt a more textured notion of the nature of science” (p. 943). Philosophers of science have long worried about the use of careless
language and thinking when discussing change in science, as evidenced by Lauden’s (1984) view that “In trying to characterize the mechanism of theory change, we [philosophers of science] have tended to lapse into sloppy language for describing change” (p. 68).

When dealing with the philosophical and epistemic ideas and concepts that define contemporary NOS studies (which are admittedly complex), care must be taken in how these ideas and concepts are stated and framed—especially in instructional contexts. As Wittgenstein reminds us, “Philosophical problems arise when language goes on holiday” (as cited in Thagard & Beam, 2004, p. 512). It is reasonable to rephrase Wittgenstein’s simile in an educational context and assert that, “Instructional problems arise when language goes on holiday.” However, recognizing linguistic and conceptual inconsistencies, problems or anomalies also provides opportunities for further elaboration and precision of understanding and meaning, which is the intent of this article. At a bare minimum, the proposition under examination here by Lederman et al. (2002) provides the intellectual fodder to demonstrate how formal logic can be applied to important assertions relative to NOS (and other areas) to determine their validity and soundness or lack thereof.

Accordingly, the next two sections of this article briefly establish the idea that NOS studies and instruction are fundamentally epistemic endeavors and that a central (epistemic) feature of scientific knowledge is the concept of tentativeness. Having established these two points, the article introduces a simplified NOS framework that is subsequently used to clarify problems with the view that “…similar to scientific knowledge, conceptions of NOS are tentative and dynamic.” The article concludes with a discussion and recap of the key points developed in this article and implications for future research in the area of NOS instruction and science education.

**NOS INSTRUCTION IS AN EPISTEMIC ENDEAVOR**

Although no standard definition of the nature of science exists, the educational literature generally associates this concept with the epistemology of science, or the values and assumptions inherent in the development of scientific knowledge (Lederman, 1992). Specifically, this epistemological view among science educators emphasizes the idea that scientific knowledge is stable yet tentative, empirically based, inferential, subjective, theory-laden, and influenced by the social and cultural milieu (American Association for the Advancement of Science, 1993; NRC, 1996). Many of these epistemic features of the nature of science identified by educators have been substantiated by professional philosophers of science (Eflin, Glennan, & Reisch, 1999) and empirically validated by a wide range of nature of science experts (Osborne, Collins, Ratcliffe, Millar & Duschl, 2003).

Broadly defined, epistemology is the study of the nature of knowledge. Psychologists have traditionally viewed epistemology as a more descriptive endeavor (i.e., understanding how people do think and reason) whereas philosophers of science view epistemology as a prescriptive endeavor (i.e., understanding how people should think and reason) (Thagard, 1988). Whether you tend more toward the descriptive or prescriptive model, epistemology is a quest to understand the nature of knowledge and the process of meaning-making by addressing fundamental problems. If NOS is an epistemic endeavor, then we need to understand what epistemology is and the types of problems it addresses. Bertrand Russell described the aim of epistemology well when he stated that the fundamental problem of epistemology is to understand “the relation subsisting between thoughts, words, or sentences, and that which they refer to or mean” (Wittgenstein, 2003, xvii-xviii). If NOS content is epistemic content, there is no getting around the need to critically analyze the words and sentences we use in NOS studies and research if we are to develop a more accurate, meaningful, and contextualized view of NOS and to reduce the likelihood of confusion among students. On this point, there is a good bit of concordance between analytic philosophy, epistemology and education—the goal to establish clear and logical connections between what we say and what we mean and hope to convey and teach—connections that represent the foundation of Dewey’s (1910/1991) educational philosophy and much of modern learning theory and cognition (Ashcraft, 2002).

**SCIENTIFIC KNOWLEDGE IS TENTATIVE**

As stated above, the tentative and revisionary character of scientific knowledge is believed to play a central role in nature of science studies by teachers, researchers, and curriculum developers. As Lederman and O’Malley (1990) point out, much of the research regarding the nature of science in an instructional context has been based on the belief that “tentativeness is the primary attribute of scientific knowledge…” (p. 225). Indeed, for the past six decades instruments designed to gauge student understanding of the nature of science have to some degree and at varying levels of sophistication involved measures of tentativeness and
change (Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002; Aikenhead, 1987; Lederman & O’Malley, 1990; Ruba & Anderson, 1978; Vitrohan, 1967; Wilson, 1954). This priority focused on the tentative, dynamic and changing nature of scientific knowledge has developed gradually over the past fifty years following developments in the history and philosophy of science and cognitive psychology and it has played an increasingly important role in science education (Duschl, 1994). Indeed, it is now somewhat of a tautology to state that scientific knowledge is stable yet tentative (whatever this may actually mean). But having established the idea that scientific knowledge is tentative and dynamic does not mean that all or most scientific knowledge is tentative at the .5 (as opposed to the .0005) level of correctness with a 50% chance of being (significantly) revised (relative to core as opposed to auxiliary theoretical principles or facts), and this same tautological claim is not the same as having established the idea that our conceptions of NOS are tentative (or even close to establishing such a claim)—even though such a claim is an intuitively appealing idea that may be true to some degree and with important qualifications as is discussed in the next two sections of this article. Making overly simplistic sweeping claims and then sweeping claims from those claims most often sweeps meaningfulness, clarity, preciseness and highly accurate assertions and claims out the door, and it is for these very reasons that we must be very cautious about sweeping claims and examine and analyze them closely in detail for both misrepresentations and problems. The next two sections of this article provide this type of rigorous analysis relative to the proposition under examination here that our general conception of NOS is tentative.

SIMPLIFIED NOS FRAMEWORK

Before addressing the logical concerns and problems relative to the view that our general conception of NOS is tentative, a simplified framework for specific NOS tenets as outlined by Lederman et al. (2002) is provided in the concept map in Figure 1 with some modifications. The general conception of NOS is identified by a node (bubble) labeled with a capital letter A and is assumed to be tentative, while the subordinate node (Epistemology of Science) is labeled with a capital letter B. Off the B node are five of the tenets of NOS identified by Lederman et al. that are numbered 1 to 5, respectively. It should be pointed out that the epistemology of science node (node B) and the five associated NOS tenets in Figure 1 are derived largely from the historical and philosophical study of science and are agreed upon by most science education researchers. Directly beneath nodes 1 to 5 are three alternate node sets (1a to 5a, 1b to 5b and 1c to 5c) that are replacement nodes for nodes 1 to 5 used to demonstrate different (logically possible) interpretations of each of the five NOS tenets as well as different reasoning paths in the concept map. Each of the bubbles in the alternate node sets in Figure 1 includes an adverb (i.e., extremely, somewhat and not) that roughly qualifies the (ordinal) degree or level to which an individual understands and believes the tenet to be present in science at some point in time. Precisely defining, exploring, mapping and validating these qualified NOS tenets or scale—either from a historical or contemporary perspective—goes beyond the scope of this article, but is a logical “next step” of this research. The adverbs are used here only to establish a differentiated conceptual framework and scale to develop the formal arguments that follow. In fact, one of the main assumptions required for the arguments that follow is that the presence of individual NOS tenets can be differentiated by degree along an ordinal scale.

As discussed next, all node sets in Figure 1 represent logically possible interpretations of science under the assumption that our general conception of NOS is tentative. The concept map in Figure 1 allows one to follow the chains of reason and logical arguments introduced in the next section of the article. The concept map also simulates the many different viable, and in some cases diametrically opposed, interpretive frameworks and schemas that can arise from the epistemic proposition under examination here. Based on results from the empirical literature in science education and cognitive psychology over the past three decades, it is reasonable to assume that a student, teacher or researcher’s preference for a particular node set (or any combination of nodes) is associated with their own epistemological standards, as well as their underlying epistemological standards for science (see Perla, 2006).

LOGICAL PROBLEMS WITH A TENTATIVE CONCEPTION OF NOS

Assuming our general conception of NOS is tentative (bubble A in Figure 1) makes it difficult to conceptualize and understand some of the possible effects of this tentativeness on the subordinate tenets of NOS (bubbles 1 to 5 in Figure 1) without some clarification. For example, let us examine tenet #1 (science is empirical) and tenet #2 (science is a human endeavor) in Figure 1 knowing the same points could be made for tenets #3 to 5. Assuming the general conception of NOS is tentative (node A), does not exclude the possibility
that science is *extremely* empirical (path A-B-1a in Figure 1) or *somewhat* empirical (path A-B-1b), or that it is *extremely* a human enterprise (path A-B-2a) or *somewhat* of a human enterprise (path A-B-2b). Certainly none of these propositions or paths in the concept map, although vague, is extraordinary, counter-intuitive or difficult to accept. However, assuming the general conception of NOS as tentative, does not exclude the possibility that science is *not* empirical (path A-B-1c) or that it is *not* a human enterprise (path A-B-2c). These latter two consequences are possible logically (even though they might strongly jolt our conceptions and schemas) because once we accept the possibility that our general conception of NOS is tentative (node A), then all subordinate tenets that constitute this general conception are subject to change also; if the subordinate tenets (by inheritance) are subject to change *with no reference to the degree or limit to that change*, then we cannot rule out the possibility that the tenets themselves can be rejected (i.e., complete change; nodes 1c to 5c). In fact, explicitly pointing out that conceptions of NOS are tentative, as Lederman et al. (2002) do, is in many ways an invitation to explore the implications of the statement (or else why point it out or make the claim).

Surely, most science education researchers who accept the proposition that our general conception of NOS is tentative appreciate the idea that although science

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*Figure 1. Simplified NOS framework with alternate node sets.*
is empirical and a human enterprise, the issues surrounding the empirical and human nature of science are subject to some degree of change and re-formulation and not complete rejection. But this more nuanced and formalized view is a view that might only be inferred by someone with extensive knowledge and experience with NOS studies, and possibly not students and perhaps not many science educators who read science education journals and papers—many of whom may take these assertions and their logical consequences too literally or not literally enough, as the case may be. Nevertheless, it is still a logical possibility and consequence that under the assumption that our general conception of NOS is tentative, that science is not empirical nor a human enterprise. To a sophisticated reader, the ambiguity and possible contradiction in these examples is perhaps tolerable conceptually or ignored, but one would have to ask why these problems exist and have the question well answered to accept or tolerate this level of contradiction. However, to a non-sophisticated reader or student these types of contradictions may be utterly confusing and highly problematic—even if they are never explicitly stated or (partially) represented by the student.

To make matters more confusing, the central tenet of NOS studies (the idea that scientific knowledge is stable yet tentative) becomes extremely convoluted under the assumption that our general conception of NOS is also tentative. What exactly does it mean to say or imply that scientific knowledge is extremely tentative (path A-B-3a) or somewhat tentative (path A-B-3b)? As mentioned earlier, different degrees, types and meanings of tentativeness and change are identified by philosophers of science, science educators and students, yet a more textured view of change does not appear to be an instructional priority despite the centrality of the tentativeness concept in NOS studies (Allchin, 2004). Further, if we presently describe our conceptions of NOS as tentative without qualification, then we are essentially saying that the tentativeness of scientific knowledge is tentative, which does not exclude the possibility that scientific knowledge is certain insofar as certainty is the contraposition of tentativeness (a strange, but logically possible consequence in this example as demonstrated in path A-B-3c). This latter position is certainly not a tenable conclusion today as there is almost universal agreement that scientific knowledge is tentative—and tentative on many different levels; indeed, if the history of science has demonstrated anything, it has certainly demonstrated that scientific knowledge is subject to varying degrees and kinds of change!

But there is a difference between saying that scientific knowledge is tentative and that our conception of NOS is tentative. As mentioned above and shown in Figure 1, the idea that scientific knowledge is tentative is but one of many possible aspects (or tenets) that constitute our general conception of the nature of science, which is a larger (meta) epistemological system and network of ideas. So when Lederman et al. (2002) (or anyone) state that “similar to scientific knowledge, our conceptions of the nature of science are also tentative,” they clearly recognize a distinction between scientific knowledge and the more comprehensive and general NOS framework. But by making this assertion, they confuse scientific knowledge with the general conception of NOS and are committed (by definition) to the possibility (however small it may be) that scientific knowledge is not tentative (nor human, empirical, theory laden or creative). The logical problem and inconsistency here is that science is largely defined as claims, assertions, views, and theories that are falsifiable (Popper, 1969) and subject to continuous modifications, alterations, refinements and rejections (Losee, 2004; Suppe, 1974). Scientific knowledge, therefore, is without question and by definition tentative, albeit to different degrees.

In other words, the tentativeness of science (from an individual NOS tenet perspective) is not and cannot be tentative (from a comprehensive and general NOS perspective) without important qualifications and limits. To argue otherwise, is to argue that our general conceptions of NOS (whatever they may be at any point in time) have little to no bearing on or relation to the subordinate propositions and tenets that define these conceptions at the operational and instructional levels (i.e., a problem of praxis). To conclude that similar to scientific knowledge our conceptions of NOS are tentative and dynamic based on transitions in historical, sociological or philosophical thinking without taking into account the subordinate propositions that define these general views is highly problematic because it creates a disconnect between the general conception of NOS and its specific and defining tenets.

The argument outlined in this section thus far suggests that our general conception of NOS may not be tentative at all at one level and is tentative at other levels only with important qualifications and a more differentiated view of tentativeness. The general argument developed here against the view that our general conception of NOS is tentative can be framed in the formal language of philosophy, specifically the form of argument known as modus tollens (see below). In fact, each of the five NOS tenets in Figure 1 can be framed using the modus tollens form to demonstrate the limitations and difficulties with the proposition that our general conception of NOS is tentative. For the sake of brevity,
I introduce, develop and discuss only one of the NOS tenets in *modus tollens* form, specifically tenet #3 in Figure 1 that addresses the tentativeness of scientific knowledge, which is believed to be the central and key NOS tenet presently by science education researchers.

We begin with the *modus tollens* form, which includes the following two premises and conclusion:

Premise (1): If P then Q
Premise (2): Not-Q
Conclusion: Not-P

This general (logical) argument form and its associated propositions is described as *a priori* (since the truth or falsity of this argument can be determined by pure reason *prior to* any observation), and *analytic* (since only the meaning of the words and not any factual content needs to be considered to determine the truth of the claim). For example, the proposition “All tall men are tall” is an analytic proposition because its truth is based only on the meaning and use of the word tall; no observations are needed to determine that this proposition is true.

Next, we “populate” and instantiate the standard *modus tollens* form with the specific content and propositions discussed earlier in this article as outlined in Figure 1. Accordingly, the “If P” region of premise (1) is populated with the assertion of Lederman et al. in premise form: “If our general conception of NOS is tentative,” while the “then Q” region of premise (1) becomes one of the consequences of this assertion established in this article and in Figure 1: “Then scientific knowledge may be absolute.” Following the *modus tollens* form, premise (2) becomes the much agreed upon (although vague and undifferentiated) statement: “Scientific knowledge is not absolute.” The conclusion that logically follows premise (1) and premise (2) is: “Our general conception of NOS cannot be tentative.”

This instantiation and population of the *modus tollens* form comes together to create a formal argument. Since it is customary in the field of logic to name arguments, I refer to this argument as the Tentative Argument and it is introduced below:

1. If our general conception of NOS is tentative, then scientific knowledge may be absolute.
2. Scientific knowledge is not absolute.

3. Our general conception of NOS cannot be tentative.

In terms of the above argument, this article established premise (1) as being true, while premise (2) is already widely accepted as being true. The Tentative Argument is a (deductively) valid argument because the premises logically imply or entail the conclusion. Because the premises are true and the argument valid, the Tentative Argument is sound. Generally speaking, sound arguments are the highest standard of argument in philosophy and formal logic because they are both logically valid and true (Curd, 1992).

What the Tentative Argument demonstrates is the central feature and aim of formal logical analysis—the study of the form, relation and implication of propositions. In accord with this view of formal logic and analysis, Kemeny (1959) states:

Thus we can sum up by saying that Logic considers the form of propositions. It starts out by considering statements. It studies the meanings of the words occurring and the rules of syntax according to which words are compounded. Finally it arrives at the abstract form of the proposition expressed by the statement. What Logic wants to know is whether a proposition of this form is necessarily true—or necessarily false. (p. 20)

Using the framework described by Kemeny, and the *modus tollens* form above, we conclude that the proposition that “similar to scientific knowledge, conceptions of NOS are tentative and dynamic” is false at the formal level of analysis and requires reformulation.

What may not be obvious, yet is critically important, in the above example and transformation is that we used the very generic and logically structured *modus tollens* template that relies on *a priori* and *analytic* propositions to develop a specific argument (the Tentative Argument) that involves less rigorous, factual and observational propositions (which are know as *synthetic* propositions). Because synthetic propositions require some observation, they are necessarily *a posteriori*. Indeed, premise (2) of the Tentative Argument is based on much factual observation and prior analysis that has convincingly demonstrated that scientific knowledge is not absolute. So the transition from the general *modus tollens* template to the Tentative Argument involves a fundamental transformation of the types of propositions used. Thus, the more formal and rigorous *modus tollens* template and form provided the logical structure and framework from which to develop the Tentative Argument and to clearly and succinctly examine some of the logical implications, inconsistencies and limitations of the view that our general concep-
tions of NOS are tentative—problems and insights that might have otherwise gone unnoticed.

And herein lies whatever value might be gleaned from a rigorous and formal (mathematical) analysis of propositions: the uncovering of new facts and limits that can be addressed and possibly expand our knowledge and the quality of our thinking. As Kemeny (1959) points out in his classic discussion of the role and virtue of mathematics, logic and propositional analysis: “...sometimes things follow from the meaning of words that are so far from obvious that it takes a good mathematician [or logician] several weeks or even years of painstaking labor to prove them” (p. 22). Kemeny goes on to note that “While in a sense mathematics [and logic] bring us nothing new, since it does no more than analyze the meanings of words, it brings us facts that are new to us, facts we did not realize we possessed” (p. 22, emphasis in original).

However, it should be pointed out that using an analytic/a priori form of analysis, although a highly useful and structured propositional template and starting point, to analyze synthetic claims does create some problems (as all transformations do), because there are different criteria for determining the validity of analytic and synthetic propositions. This concern and issue is addressed effectively by Ayer (1952) in the following passage:

In saying that we propose to show “how propositions are validated,” we do not of course mean to suggest that all propositions are validated in the same way. On the contrary we lay stress on the fact that the criterion by which we determine the validity of an a priori or analytic proposition is not sufficient to determine the validity of an empirical or synthetic proposition. For it is characteristic of empirical propositions that their validity is not purely formal. To say that a geometrical proposition, or a system of geometrical propositions, is false is to say that it is self-contradictory. But an empirical proposition, or a system of empirical propositions, may be free from contradiction, and still be false. It is said to be false, not because it is formally defective, but because it fails to satisfy some material criterion. And it is our business to discover what the criterion is. (p. 90)

As Ayer clearly points out above, it is important to recognize and conceptualize the differences in the criteria we use to assess and formally validate analytic and synthetic propositions. The Tentative Argument clearly involves factual (synthetic) propositions (i.e., the observations and related statements that scientific knowledge is not absolute but tentative), the validity of which cannot be purely derived from formal analysis (at least not entirely). However, the Tentative Argument also addresses and brings to light an important self-contradiction relative to the general conception of NOS and its defining tenets, and formal analysis is well suited to frame and isolate such contradictions, as this article demonstrates. Understanding exactly what happens to synthetic propositions when placed in an analytic model is still an unresolved issue in philosophy (and may always be such), but suffice to say there is a place for formal analysis in identifying and representing problematic, inconsistent and self-contradictory propositions in NOS research and educational research in general.

The critical linguistic model and approach used in this article is not presently a common form of analysis in science education research. The main thesis of this article suggests that formal propositional analysis may serve an important function as a tool to analyze research in science education, and it is most certainly a method that compliments NOS studies (with its focus on epistemology and philosophy) and science education (with its focus on critical thinking and scientific literacy). The formal method used here (which is extremely critical, formal, and focused) contrasts the method used by Lederman et al. relative to the proposition under examination here (which is extremely vague, informal and slogan-like). Although it might be reasonable to meet somewhere in the middle of this continuum, science education researchers have yet to establish a priority with a more formal and rigorous mode of expressing, analyzing and representing key NOS ideas and terms to one another or to students (i.e., the context of justification). These issues and related concluding remarks are briefly elaborated upon in the discussion section next. The aim of the discussion that follows is to bring the key ideas developed in this article full circle back to concerns of education and educational research, and in particular, NOS research.

**DISCUSSION**

This article examined the very critical and key generalization or contention that our conception of NOS, like our conception of scientific knowledge, is tentative and dynamic. This assertion seems reasonable and to be a generalization as claimed when we consider that the different aspects of NOS (such as the creative, human, and empirical aspects) are subject to change to some degree and in specific contexts. For example, future studies may provide evidence to suggest that scientific
knowledge is more or less creative, empirical and theory-driven than presently thought (although these are certainly difficult things to measure precisely). The possibility of these small scale or local types of changes are accepted and even expected by most NOS scholars and researchers and are not being questioned here. However, if followed through to its logical consequences (as all generalizations should be in science and other areas) and without limits and clarification, a tentative conception of NOS does not exclude the possibility of completely rejecting each aspect (or tenet or idea or concept) of NOS, regardless of how slim that possibility might be. It is extremely difficult to imagine science as non-empirical, non-human and theory-less. However, it is even more difficult to imagine that the tentative nature of science is tentative (without important qualifications), as this position clearly suggests that scientific knowledge could be viewed as absolute and certain (or something less than tentative). Could anything fitting this profile continue to be called science as we know it today? These are some of the potential “wrong turns” and misconceptions afforded to anyone who considers the view that our conception of NOS is tentative. These facts strongly suggest that this claim is not a well worked out, well constructed, and thoroughly examined generalization as asserted, but rather is a slogan and an example of sloganeering, or at least well along the road to that end of this contrasting continuum. Matthews (1997, 2005) and others (e.g., Alchich, 2004; Carefi, 2005; Fenham, 2004) have written fairly extensively about this problem in science education and elsewhere and the many and important consequences of slogans and sloganeering as opposed to well constructed and thoroughly examined generalizations which will be addressed in more detail below. The point focused on here, however, is the many and convoluted logical inconsistencies of this assertion and claimed generalization about NOS and its potential for generating and contributing to misconceptions.

These logical inconsistencies, if noticed at all, are perhaps less of a problem for the sophisticated scholar, educator or reader who may be more capable of dealing with and overcoming conceptual ambiguity or recognizing and dealing with slogans as opposed to well constructed and thoroughly examined generalizations. The concern here, therefore, is with the unsophisticated reader who knows enough to try to follow a chain of thought, but does not have the sophisticated knowledge structures to overcome these logical problems. Since we know that students and many teachers have difficulty with epistemic terms and concepts, great care should be exercised in constructing and using such terms and concepts—especially when they are used or proffered as generalizations (as opposed to slogans).

In their advocacy of teaching NOS, science education researchers have attempted for the most part to avoid intractable philosophical debates. This is why Osborne, Collins, Ratcliffe, Millar and Duschl (2003) accept a “vulgarized” (simplified) view of NOS and why Lederman et al. (2002) state that “many disagreements about the specific definition or meaning of NOS that continue to exist among philosophers, historians, sociologists, and science educators [such as the existence of an objective versus a phenomenological reality] are irrelevant to K–12 instruction” (p.499). But just how vulgarized (even using a subjective and ordinal metric) can our perspectives become and what are the consequences of such perspectives in the classroom? That said, it is interesting and somewhat surprising that Lederman et al. (2002) would address a point and generalization that, as has been shown here, is philosophically and epistemically complex and presumably, in their opinion, irrelevant to K–12 instruction.

It should also be noted at this point that philosophically complex ideas have an insidious way of worming their way into our thoughts and actions despite our best attempts to keep them “neutralized” (Bartlett, 1932; Ryle, 1949). This “worming effect” of philosophically complex ideas is especially important to consider when developing instructional materials related to NOS where it can be assumed that K–12 students (and even college and pre-service students) are more susceptible to such effects and associated misconceptions (both unconsciously and consciously formed) due to their lack of philosophical training and experience.

The title of this article asked if our conception of the nature of science can be tentative. The answer is that our general conception of NOS can be viewed as tentative as it relates to the many different NOS aspects (or tenets) in most instances, acknowledging the fact that the logic of this statement is flawed to some degree (which would seem to be a very helpful instructional point). However, this generalization is extremely problematic when applied to the core aspect (or tenet) of NOS studies—the tentativeness of scientific knowledge. But K–12 students and teachers do not need to consider or reconcile “the tentativeness of tentativeness problem” in order to develop a sound appreciation and understanding of NOS.

So how can the logical problems associated with the tentative conception of NOS be balanced against the advantages to studying NOS (without just ignoring the criticisms in this article)? I have four recommendations to address this issue:
First, if science educators prefer to adopt a simplified view of NOS, as many now do, then overreaching generalizations like the one analyzed here should not be made lightly or in passing. Indeed, in discussing Wittgenstein’s view of philosophy, Richter (2006) makes the following statement about generalizations that applies equally well to education as it does to philosophy: “When nonsense is spoken or written, or when something just seems fishy, we can sniff it out. The road out of confusion can be a long and difficult one, hence the need for constant attention to detail and particular examples rather than generalizations, which tend to be vague and potentially misleading [italics added]” (p. 6). This quote suggests, as does this article, that science educators and educators in general need to be careful when making generalizations about NOS and to anticipate ways in which what we say and teach can be misunderstood by learners.

Second, science educators should not operate and teach under the assumption that our conception of NOS is tentative but rather operate and teach under the assumption that our conception of NOS is non-controversial (a term used by Lederman et al. (2002) to describe the five tenets of NOS in Figure 1). For example, it is less problematic to accept and teach the idea that “tentativeness in science is non-controversial” versus the idea that “tentativeness in science is tentative.” That said, a more fine-grained analysis of tentativeness and change is needed in NOS studies and research. Indeed, until the word “tentativeness” includes qualifiers relative to degrees (i.e., how tentative and what is the probability of change, as suggested briefly in Figure 1) it is almost a totally meaningless and empty word, concept and statement as the ambiguity and range of possible meanings is to too great and too different for students (and even researchers) to effectively conceptualize.

Third, science educators and particularly NOS researchers should consider and recognize that science and philosophy have very different forms and standards of discourse (Thagard & Beam, 2004) and be aware of possible logico-linguistic inconsistencies and misconceptions related to NOS studies and instruction.

Fourth, NOS researchers need to understand that our general views and conceptions of NOS need, at very minimum, to be logically consistent with the individual tenets that define and operationalize the general conception(s) to whatever extent this logical consistency is possible. Indeed, this type of logical consistency between the general and the specific features of a construct is actually a form of internal validity that also influences important issues relative to construct validity and generalizability (Kerlinger & Lee, 2000). In cases where inconsistencies between a general proposition and its defining elements are identified, qualifications and exceptions need to be clearly articulated and discussed. Of course, none of these recommendations is easy to realize, especially in the classroom, but awareness of these issues is likely to be helpful in NOS instruction, research and assessment.

Lastly, this article attempts to dissect, analyze and reflect on a critical and key assertion made by science educators related to a central feature of NOS studies (i.e., tentativeness). Ironically, this specific exegesis and analysis is the same type of qualitative and exploratory strategy recently advocated by leading science education researchers to better understand students’ views and statements of the nature of science. In fact, one of the virtues of the View of Nature of Science (VNOS) questionnaire developed by Lederman et al. (2002) is its ability to perform more in depth and contextualized studies of specific comments, propositions and assertions made by students relative to NOS—a purported limitation of the strictly quantitative assessment models. Because of the inherent complexity and subtlety of language, especially philosophical and epistemic discourse, NOS researchers stand to gain from routinely applying the critical linguistic-conceptual analysis of statements made by students to their own statements and views. As Wittgenstein notes—and as many NOS and science education researchers have indirectly documented and experienced: “Language sets everyone the same traps; it is an immense network of easily accessible wrong turnings” (as cited in Richter, 2006, p. 7). Perhaps by paying closer attention to the language we use in NOS studies and research we can do a more effective job teaching students about the nature of science by anticipating misconceptions (or “wrong turnings”) and developing more coherent, differentiated and satisfactory instructional models of NOS.

In a word, we need to employ well-formulated, well constructed, and thoroughly examined generalizations, assertions, concepts, and claims about NOS and its various components as opposed to vague, ill-defined and logically problematic ones that upon examination quite clearly turn out to be no more than slogans, quasi-slogans or statements very close to these kinds of statements with all of their many associated and undesirable consequences and problems for both NOS and science education in general. More work clearly needs to be done in developing more contextualized and coherent theoretical views and models of change as a whole in science education versus “fact points” or “fact islands,” that are essentially behaviorist views of scientific knowledge.
and knowledge in general and consequently the learning and understanding of both. Research along these lines is currently under way.

REFERENCES


Educational Resources

The Role of Schemas in Mathematical Problem Solving

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This paper is the result of a directed study in reasoning and problem solving during the spring of 2006. Upon completion of the course Reasoning and Problem Solving in Mathematics and Science in the fall of 2005, I decided to broaden my knowledge of schema development as it relates to mathematical problem solving. After careful exploration of the term 'schema', the present research on the relationship between schema and problem solving is discussed. The research includes the use of analogy, worked out examples, and structural features to a given mathematics problem. Instruction for schema development is also explored. The results of the research indicate that schema development plays an important role in the capacity to solve problems in mathematics.

The purpose of this paper is to explore the development of schema theory in relation to mathematical problem solving. First, the evolution of the term is explored. The historical and philosophical roots play an important part in the use of the word and, more importantly, in the research concerning schemas and their role in psychology and education. Richard Mayer and Sandra Marshall both state clear and useful definitions for the term schema as well as delineate the types of knowledge required for schemas. The views of each researcher will be explored and compared. Next, the research regarding schema formation and its relationship to mathematical problem solving will be explored. Finally, the instructional implications from the research will be discussed.

EVOLUTION OF THE TERM ‘SCHEMA’

HISTORICAL DEVELOPMENT

The definition and use of the term schema has evolved over time. The term has been used differently by a multitude of authors, creating the possibility for confusion and misrepresentation. Marshall (1995) suggested that the term schema is the literal, letter for letter translation of the Greek term σχήμα. The term σχήμα appears many times in the writings of Plato and Aristotle. Though most commonly translated into English as form, posture, shape, or figure, Plato uses the term in numerous ways in a variety of contexts (p. 4). Marshall asserted that by using the term in this manner, “Plato is reaching for broad generalizations, not specific details” (p.5). Plato starts using the term while discussing the inherent nature of objects then moves to using the same term in discussions concerning abstract concepts. Plato develops the use of the term schema into “the sense of a general framework or basic outline” (p.7).

Aristotle uses the term σχήμα frequently in his Metaphysics most notably in two ways (Marshall, 1995). In a similar manner to Plato, Aristotle first discusses σχήμα as geometric or physical shape (p.6). Later, he introduces the concept of categories to the usage of σχήμα or schema. Although the term categories usually appears in Metaphysics as its direct Greek translation, στοιχεῖα. When Aristotle refers to categories as an entity, he uses the plural form of στοιχεῖα or στοιχεῖα. For Aristotle, these categories refer to organizing characteristics that “allow recognition and understanding of basic properties” (p.7). It is important to note that much of the depth and character of the term σχήμα has been lost with the common translations of shape and form and it is obvious that Plato and Aristotle had a much larger picture in mind than the traditional translations yield.

Immanuel Kant contributed greatly to the exploration of schema. Unlike his Greek predecessors, Kant was interested in the schema itself, not the objects or ideas the schema was describing (Marshall, 1995, p.7). Kant believed that there exists in everyone a body of innate or a priori knowledge. He also believed that our sensory experience needed to be interpreted by this a priori knowledge. For Kant, the schema is the key for using our a priori knowledge to understand our sensory experience (p. 8). A person’s schema acts as the link between innate knowledge and perceived experience. Marshall suggests that it “provides the representation of the perceived phenomenon which can then – and only then – be interpreted under the general restrictions of the innate categories” (p. 8). Kant’s work has had a lasting impact. Most researchers studying schema theory view schemas as the link between concepts and perception (p.8). But, unlike Kant, the link is seen between concepts in memory and experience, not a priori knowledge and experience.
**Contemporary Definitions**

The field of cognitive psychology has contributed greatly to the development and definition of schema theory. Richard E. Mayer (1992) asserts that the definition of schema needs to include four aspects:

- General – a schema may be used in a wide variety of situations as a framework for understanding information;
- Knowledge – a schema exists in memory as something that a person knows;
- Structure – a schema is organized around some theme;
- Comprehension – a schema contains ‘slots’ that are filled by specific information (p.228).

For Mayer, schemas provide “an integrated, meaningful framework” for the selection and organization of new information (p. 228). One’s schema is the structural framework that contains both the knowledge and understanding of a concept. According to Mayer, research on schema theory consistently shows that people remember the crux of story not the verbatim language. He also finds it noteworthy that people tend to remember important information that is consistent with their perspective rather than contrary (p.258).

In recognition of the rich past and present research interest, Sandra Marshall (1995) sought to create a substantive definition of schema. Marshall seeks to create not only a definition for the term schema, but also an informal theory. The different functions of a schema are explored as well as the types of knowledge required for schema use and instantiation (p.39). Marshall asserts the following:

A schema is a vehicle of memory, allowing organization of an individual’s similar experiences in such a way that the individual

- Can easily recognize additional experiences that are also similar, discriminating between these and ones that are dissimilar;
- Can access a generic framework that contains the essential elements of all these similar experiences, including verbal and nonverbal components;
- Can draw inferences, make estimates, create goals, and develop plans using the framework; and
- Can utilize skills, procedures, or rules as needed when faced with a problem for which this particular framework is relevant. (p.39)

Marshall continues with the assertion that each of the above schema functions requires a different type of knowledge: identification knowledge, elaboration knowledge, planning knowledge, and execution knowledge.

In the following section, the different types of knowledge required for schema formation will be explored. Marshall (1995) and Mayer (1992) both delineate different knowledge types, but each categorizes them differently.

For Marshall (1995) identification knowledge enables pattern recognition (p.40). Pattern recognition does not develop as the result of a single feature, but the processing of many features. The result is the ability to recognize an experience. Elaboration knowledge is declarative knowledge usually containing specifics from one’s own experience (p.40). It contains verbal, visual, and sensory information “enabling an individual to create a mental model about a current problem” (p.40). Identification and elaboration knowledge work together to enable one to create a hypothesis about an experience and test it.

Marshall (1995) asserts that planning knowledge enables one to create plans or strategies. It is acquired through experience and updated regularly (p.41). Marshall also asserts that “recognizing that a schema may be used in a particular problem solving situation does not necessarily mean that it can automatically be channeled into complex plans” (p.41). Having the declarative knowledge or plan is important, but knowing what to do with it is equally important. There is a distinct difference between creating a plan and having the ability to carry out a plan. Marshall refers to execution knowledge as the knowledge that “consists of the techniques that lead to action, such a performing a skill or following an algorithm” (p.41).

Marshall (1995) also discusses the structure and substance of schemas. They are flexible storage devices interconnected with a network structure. A schema may be accessed through many channels; they are a variety of sizes and overlap (p.46). Individuals construct their own schema as a result of repeated experiences. They enable problem solving and involve analogical reasoning (p.57). It is interesting to note Marshall’s frequent reference to problem solving. The purpose of schema formation and acquisition is to acquire the knowledge and skills necessary to solve problems.

In contrast, Mayer (1985, 1992) sets forth his own categories of required knowledge. He discusses these types of knowledge as required in the context of problem solving, as Mayer sees schema theory under the umbrella of problems solving. Five different types of
knowledge are separated into two groups, problem representation and problem solution. Problem representation requires linguistic, semantic, and schematic knowledge (Mayer, 1992, p.458). Linguistic knowledge is the knowledge of one's language. It consists of the capacity to recognize the meaning of words. Semantic knowledge refers to factual information about the world. Linguistic and semantic knowledge work together in the process of translating a problem into an internal representation (Mayer, 1985, p.125). Schematic knowledge or knowledge of problem types enables the combining of information into a coherent whole (Mayer, 1992, p.459). Problem solution can be broken down into two types of knowledge, strategic knowledge and procedural knowledge. Strategic knowledge refers to the knowledge of how to use one's knowledge in the planning and monitoring of solving a problem. Procedural knowledge refers to the execution of a problem solving plan (p.459).

Mayer and Marshall differ in their views of the relationships among schema, knowledge, and problem solving. Marshall (1995) defines the schema as a vehicle that performs functions for the individual. Each of these functions, including problem solving, utilizes different types of knowledge. The theory she sets forth allows one to view a schema and the knowledge required for the schema as two separate entities. Mayer (1992) sets forth a different relationship. Schemas are defined as frameworks for organization. They contain both knowledge and understanding. Mayer asserts that schemas are an aspect of problem solving, while Marshall sees problem solving as one of the many functions of a schema. Both define quite similar knowledge requirements, though Marshall asserts that the knowledge required for schema “may be defined and studied separately as well as compositely” (Marshall, 1995, p.39).

THE DEVELOPMENT OF THEORIES FOR SCHEMA-BASED LEARNING

This section will focus on the theoretical roots of schema based learning. Bartlett and Piaget created theories of learning and knowledge acquisition that resonate today. Though the terms Bartlett uses to frame his theory lack clear definition, he certainly started a conversation about memory and learning. Piaget continued with the exploration of intellectual development. It is Piaget who is credited with the development of a comprehensive theory of learning.

BARTLETT’S ‘EFFORT AFTER MEANING’

In the 1930s, British psychologist Fredric Bartlett focused his research “on how individuals remember and what they remember” (Marshall, 1995, p.9). Bartlett (1932) developed a theory of remembering, stating that “the mechanism of adult human remembering demands an organization of ‘schemata’ which depends upon an interplay of appetites, instincts, interests, and ideals” (p.309). Bartlett commented extensively on the term schema. He stated that the definition lacked precision and attempted to clarify the term’s meaning. For Bartlett, “schema’ refers to an active organization of past reactions, or past experiences” (p.201). Bartlett asserts that a schema is activated by a new story. This new story is then adapted or changed to fit existing schema while being placed in memory. Later, when the story is recalled, only the adapted one is available for recall therefore losing aspects of the original story. Bartlett’s attempt at clarifying the term schema is still lacking as it is narrowly focused on memory. Bartlett is credited with delineating two ideas about memory (Mayer, 1992, p.229). The first is that when material is learned and stored in memory, it is not duplicated exactly. The second is that memory is schematic and not detailed. Bartlett is also credited with the concept that an individual desires to make sense out of new experiences using prior experiences. He refers to this as ‘effort after meaning’ and suggests that this active structure guides memory and reasoning (Bartlett, 1932, p.44). By seeking to make sense of environment, one is making an effort after meaning. One of the important aspects of Bartlett’s work is that one is actively engaged in the ‘sense making’ process.

PIAGET’S ACCOMMODATION AND ASSIMILATION

Jean Piaget is credited with creating “one of the best-developed theories of schema-based learning” (Marshall, 1995, p.13). Piaget described the schema as a completely coordinated set of physical actions and cognitive functions, a set that worked together in its totality to respond to every perceived experience that could be related to the schema” (as cited in Marshall, 1995, p.14). It is important to note that Piaget’s definition includes physical action, and thus involves behavior. To function effectively, schemas need to be flexible and cohesive. Piaget (1936) asserts that schemas are only constructed for experiences that happen repeatedly (p.246). As new experiences occur, “every newly established connection is integrated into an existing schematism” (Piaget & Inhelder, 1969, p.5). An experience may need to be modified to fit a schema and the
modified experience becomes part of one's schema. The process of “filtering or modification of the input is called assimilation” (p.6). When an experience cannot be modified to fit an existing schema, the internal schema itself will need to be modified. This is the process of accommodation (p.6). Piaget points out that with more experiences the schemas become more generalized, their individual characteristics become less important, and they can be applied to a larger range of situations (Marshall, 1995, p.15).

Piaget has had an enduring impact on the study of cognition, especially with his assertion that one actively constructs their reality (Marshall, 1995, p.15). In the process of interacting with the environment, one adapts experience for existing schema or creates new schema based on experience. Marshall points out that Piaget refers to this desire to make sense out of one's environment as equilibrium (p.15). Piaget (1936) also asserts that there exists a reciprocal relationship between one's schema and the environment (p.244). Schemas aid one in the understanding of an experience. These schemas may be augmented with new experiences or changed as a result of an experience.

There are very many similarities between Bartlett's and Piaget's ideas and assertions. Bartlett and Piaget assert the importance of active engagement. Bartlett (1932) discusses the importance of active engagement in the sense making process (p. 20). Piaget (1959) discusses the importance of one being actively engaged in constructing reality through experience (p.365). Bartlett and Piaget both discuss the aspect of interaction with the environment. For both theorists, the process of active engagement must happen within one's environment. Bartlett and Piaget stress the need to make sense of one's environment. Also, the concept of modification is important to both Piaget and Bartlett. Bartlett (1932) discusses that a story is modified to fit into an existing schema and when it is recalled, it is only available in its modified form (p.205). Piaget develops this component of his theory with much more detail than Bartlett. This modification process is a central aspect of Piaget's theory. For Piaget, the state of equilibrium is achieved through the constant processes of assimilation and accommodation. To make sense out of one's environment, either the information needs to be modified or the schema receiving the information needs to be modified.

**Present Research on the Relationship Between Schema and Problem Solving**

When examining the present research on schema in mathematical problem solving, several themes became apparent. First, research has been conducted connecting the use of analogy and problem solving success. Another avenue has examined the differences between the surface and structural characteristics of mathematics problems and how those characteristics can impact the success of problem solvers. Lastly, the use of worked out examples as an instructional technique was examined in relationship to mathematical problem solving success. Overarching all of the research is the notion that when one creates a more effective schema, then one can engage in more effective problem solving (Cooper & Sweller, 1987; Cummins, 1992; Gick & Holyoak, 1983; Hegarty, Mayer, & Monk, 1995). Hegarty, Mayer, and Monk (1995) link the successful problem solver with the construction of a mental model or schema. They found that successful problem solvers used a meaningful approach or a problem model approach (p. 19). This approach required that the problem solver create a mental model for the problem situation and use the model for the problem solution.

**Problem Solving Via Analogy**

In their ground-breaking work, Gick and Holyoak (1980, 1983) lay a foundational link between the role of analogy in problem solving and schema development. In their initial work, Gick and Holyoak (1980) sought to “investigate the use of analogies between disparate domains as a guide to finding solutions for an ill-defined problem” (p.307). Five different experiments were conducted. In all five experiments, subjects were given story analogies and then asked to solve another problem. The story analogies are stories that contain a problem whose solution could be analogous to another. There were a few variables manipulated over the five experiments: whether or not the story analogy contained the solution to the stated problem, whether or not the subjects were given verbal clues to use the given story analogy solution path as a model for solving the given problem, and the number of given story analogies. The findings for this study showed that prompts, either verbal or written, enabled students to recognize an analogous solution to solve a new problem (pp.330-331). The researchers interpreted this to mean that problem solving via analogy is a conscious process where memory plays an important role (pp. 331, 349). The researchers also concluded that these “results substantiate anecdotal descriptions of the role that analogical thinking may play in creative problem solving, and at the same time provide some information about the mental processes involved in analogical problem solving” (p.346).
Though this research is an important beginning, the language used throughout the research lacks clear definition. First and foremost, the title of the paper, *Analogical Problem Solving*, never gets defined. The reader is left to surmise the authors’ intent. Also, the researchers state that one needs to use semantic knowledge to complete an analogy, while the definition for semantic knowledge is assumed (p. 313). It is also important to note that in the final three paragraphs of the paper, the researchers start using the terms ‘schema’ and ‘schemata.’ Again, these terms are not defined and appear to be used interchangeably. The term ‘mapping’ appears several times in reference to an analogy, but no reference to its meaning is given.

In a similar research project, Gick and Holyoak (1983) explore the role of schema and its relationship to the use of analogies to solve problems (pp. 2,3). Six different experiments were conducted. In all six experiments subjects heard a story that contained a problem and a solution. Subjects were asked to solve an analogous problem without any hint to use the solution path from the previous problem. If students did not solve the problem using an analogous solution, they were asked to verbally propose another solution to the problem. The variables that were manipulated included: whether or not students were asked to verbally recall the initial story analog before being asked to solve a new problem, whether the story analog contained a statement stressing the underlying solution principle, and whether or not the story analog contained a diagram (p.14). The findings of this study are quite interesting. First, being asked to first recall and summarize a story analog before being asked to solve a similar problem has no effect on one’s ability to recognize and use an analogous solution method (p.14). Also, adding a statement in a story analog that clarifies the solution principle does not guarantee the use of an analogous solution path (p.17). Diagrams only had an effect on the use of analogous problem solving when subjects were specifically told to use the diagram to help them solve the problem (p.19). In the last three experiments, the first three experiments were repeated only with two story analogs given in each setting. It was found that only the subjects who were given two analogous story analogs and who also wrote good descriptions of the stories similarities before they were asked to solve another problem were able to solve the subsequent analogous problem (p.25). The last two experiments found that when two story analogs are used, both a clarifying statement about the underlying principles and diagrams accompanying the story analog impact one’s ability to solve using an analogous solution path (p.29). The key finding rests in the use of two story analogs to foster the use of problem solving via analogy.

Gick and Holyoak (1983) do a better job defining the terms used in this research, but much is left open for reader’s interpretation. There is a clearer definition of analogic thinking and mapping given: “the essence of analogical thinking is the transfer of knowledge from one situation to another by a process of mapping – finding a set of one-to-one correspondences (often incomplete) between aspects of one body of information and aspects of another” (p. 2). Unfortunately, Gick and Holyoak’s attempts to link problem solving via analogy and schema still fail to provide any coherent definition of the term schema. There are small glimpses into its meaning throughout the paper, but the reader is left constructing their own meaning. Also, it appears to be an interesting jump from problem solving via analogy to schema induction and formation without a clear meaning of most of the terms used. Despite the shortfalls of the research, Gick and Holyoak appear to have opened the door for further research into the connections between schema formation and problem solving success.

Using Gick and Holyoak (1980, 1983) as a theoretical foundation, Cummins (1992) investigates the role of analogical comparison in the development of problem categorization. The hypothesis is that analogical reasoning may provide the key to problem categorization by structural features (p.1103). In the first experiment, forty-eight students are divided into four groups; verification, recognition, analogy, and schema. The verification and recognition groups are given problems focusing on the surface features of each problem while the analogy and schema groups are given problems focusing on the structural features between the problems. Each group practices with different problem types and is asked leading questions depending on group assignment. The verification and recognition groups are asked leading questions regarding surface features while the analogy and schema groups are asked questions regarding the structural features. Students are then asked to categorize the problems given as well as additional new problems (pp.1115,1116). It was found that the groups of students who were lead to focus on the structural features were better able to categorize problems along structural lines. The analogy and schema groups performed better than the verification and recognition groups. In this research article, there is an issue of the terms being used. It is quite difficult to discern the difference in treatments between the analogy group and the schema group. It appears that there may only be a subtle difference between the two groups. It is stated that the schema group was given category descriptions while the analogy group was not. It
appears to be left to the reader that the analogy group would need to create the categories themselves (p.1105).

The next two experiments focused on the differences between analogy and schema. Students were divided into three groups, verification, analogy, and schema. In the last experiment, an expert group was added. Practice problems were given based on their group selection as in the previous experiment. Feedback on the practice problems was provided when practice was complete. Students were then asked to categorize problems and record reasons for their sorting decisions (p.1112). Again, students who focused on problem structures analogically and with abstract descriptions (schema questions) outperformed those students who did not (p.1119). The researcher found that “students who engaged in analogical comparison seem to have developed a better understanding of the problems, as demonstrated by the clarity of their problem descriptions and their ability to construct coherent mathematical representations of the problem structures” (Cummins, 1992, p.1119).

**Structural versus surface features in problem solving**

Many researchers explore the premise that each problem has two components, the surface component and the structural component. The surface component refers to the specific story features of a problem where as the structural component refers to the inherent mathematical procedures required for solving a problem (Quilici & Mayer, 1996, p.144). Structural awareness is a problem solving skill where one can recognize that a problem being solved presently can use the same solution methods as a previously solved problem (Quilici & Mayer, 2002). The research shows that developed structural awareness distinguishes a successful problem solver from an unsuccessful problem solver (Blessing & Ross, 1996; Cummins, 1992; Quilici & Mayer, 1996).

It is interesting to note that the research does show that a successful problem solver’s schema may still contain some surface features, especially with newly acquired schema (Bernardo, 1994; Blessing & Ross, 1996).

In a study examining the role of examples in problem categorization, Quilici and Mayer (1996) focus on worked out examples in an introductory undergraduate statistics course. In the first of three experiments, students were given groups of worked out problems. The experimental group was given examples that had been pre-grouped by problem type, as determined by the type of statistical test required for the given data. The control group’s examples had not been pre-grouped according to statistical test. Then after students had an opportunity to review the worked out examples, they were asked to sort a new batch of problems according to problem type. The experimental group that had been given worked out examples sorted according to problem type was more successful in problem categorization. In the next two experiments, a group of students were given worked out examples to review. Half of the group received examples that stressed the problems surface similarities and half of the group was given examples that stressed the structural similarities of the problems. After reviewing the given examples, students were asked to sort a new batch of problems according to problem type. The variables that were manipulated were the number of worked out examples given and the ability levels of the students. The findings state that students who had been given worked out examples that stressed structural similarities were more successful in the categorization of problems that students who were given examples that stressed surface features. This was true regardless of the ability level of the student.

Mayer’s definition of schema is nested in this research. Mayer (1992) asserts that one’s schema is dependent on schematic knowledge. For Mayer, schematic knowledge is not only knowledge of a problem type but also the ability to combine information into a coherent whole (p.459). Quilici and Mayer (1996) work from the assumption that “schema formation depends on recognizing structural similarities among problems” (p.144). The researchers conclude that “exposure to examples influences students’ structural schema construction (p. 157).

In research that sought to explore the relationship between a problem and its related schema, Bernardo (1994) asserts that one’s schema will contain problem-specific information in regards to surface features. Bernardo fails to define the terms schema and schema, but creates his own definition of the term problem type schemata. He states that people organize knowledge into problem type categories. “Knowledge about the problem categories includes information about the relevant underlying principles, concepts, relations, procedures, rules, operations, and so on. These coherent bodies of knowledge about problem categories are called problem-type schemata” (p.379). Bernardo continues by stating that

in studying the nature of problem-type schemata, it is probably not better to be constrained by the ‘objectively correct’ definition of schema. Instead, the inquiry focused on working toward
a definition of problem type schemata that is consistent with how people use schemata in problem representation and categorization, in analogical transfer, and in other aspects of schema-driven problem solving (p.380).

In his research, Bernardo conducts four experiments where students have the opportunity to study problems and their worked out solutions before being asked to solve another problem. In half of the cases, students were given clues that reinforced surface features. “These experiments were designed to show that problem solvers synthesize problem-specific information into problem-type schemata, and that they do so in a functional manner” (p.390).

Bernardo asserts that his findings are inconsistent with the findings of Gick and Holyoak (1983) and Cummins (1992). This is an interesting assertion. Both Gick and Holyoak (1983) and Cummins (1992) researched structural features and stated the importance of structural features in analogical problem solving, but neither state that there exists an absence of surface features. There is also the issue of the definitions of terms. Bernardo has created his own definition, clearly departing from the traditional usage. Therefore, to compare the findings of his research with research that has defined its terms in another manner is highly questionable. It is also important to note that the subjects in Bernardo’s (1994) research are undergraduates from Yale University, so the generalizability of his results is questionable.

Blessing and Ross (1996) also explored the effects on problem content on problem solving success. In experiments that linked a problem’s content to its structure, Blessing and Ross were able to demonstrate that the content of a problem influences an experienced problem solver. When problems were written so that the content of the problem was highly correlated to its structure, experienced problem solvers were successful in both solving and categorizing the problem by problem type. When problems were written so that the content was not correlated to the structure of the problem, experienced problem solvers had difficulty both categorizing and solving the problems.

**Worked out examples**

In work that has become central to the study of schema formation, Cooper and Sweller (1987) assert that schema formation and algebraic rule automation are key ingredients for mathematical problem solving success. Across four different experiments, students were given explanation sheets with worked out examples. All the examples were discussed to ensure that all students understood the examples and the algebraic rules involved. Students were then asked to solve another set of problems. The variables that were manipulated in these experiments included whether or not the second set of problems included worked out examples, the amount of time given with the explanation sheet, the ability group of the students, and the teaching methods implemented. Across all of the experiments, the researchers found that students who worked with worked out examples performed better on subsequent tasks. Students who had the opportunity to use worked out examples also used less time on subsequent tasks and committed fewer errors. Though students who had more time to explore the worked out examples performed better than students whose time was shorter, the researchers interpreted this finding as a signal that rule automation and schema formation take time to develop. They state that there exists an interconnection between schema formation and rule automation. Their research showed that experience with worked out examples facilitated rule automation and thus enabled mathematical problem solving transfer. Many researchers (Paas, 1992; Quilici & Mayer, 1996; Robins & Mayer, 1993) followed this path with similar findings.

In a small study, Paas (1992) asserts that students who practice with worked out problems or partially worked out problems will exert less effort and require less instructional time. Paas uses a computer based training session to test the hypothesis. Students are randomly assigned to three groups, the conventional problem group where students solve the entire problem, the partially worked out problem group where students complete a problem that has been partially solved and the worked out problem group where students work with completely worked out problems (p. 429). Students are given the opportunity to practice with a set of problems, and then tested on a different set. The amount of practice time is recorded and students complete a questionnaire concerning the amount of effort required to solve the problems. Paas finds that students who experienced worked out problems or partially worked out problems yielded better test results and reported the lowest effort. He further concludes that students who experienced worked out problems used less effort to solve the problems and perhaps had more time and capacity for schema formation (p.433).

Robins and Mayer (1993) proposed that schema formation requires two conditions, that schematics relationships are made obvious to the learner and that the learners memory is not overloaded in the learning process (p.530). Robins and Mayer designed three dif-
ferent experiments involving 276 college students. Students were randomly assigned to four different categories, schematic/high load, schematic/low load, non-schematic/high load, and non-schematic/low load. In the schematic condition, problems were blocked by problem type and instruction regarding problem type. The non-schematic condition had problems in random order and did not include instruction as to problem type. The low load groups received worked out problems where the learner’s attention could be spent on understanding. In the high load group, students were required to do each problem. In this group, students spent time creating the relationships and solving the problem and had less time and cognitive availability for understanding (p.531). Each group received a computer simulation practice session according to the group assignment. After the simulation, all students received a problem solving test. The results showed that students in the schematics/low load group had the lowest error rates across all three experiments (p.534). Robins and Mayer use these findings to support the assertion that in a schematic/low load condition, learners are more likely to engage in schematic processing (p.536). It is important to note that both conditions are required for schema induction. A learner must have schematic instruction where problem relationships are made obvious to the student and practice with worked out examples (p.537).

In research discussed previously, Quilici and Mayer (1996) added to the research on the use of worked out examples. They found that schema formation was greatly influenced by exposure to worked out examples. Their research found that worked out examples had an even greater effect when they emphasized the structural characteristics of the problems (p.157).

**SCHEMA BASED INSTRUCTION**

**Theoretical issues**

Marshall (1995) asserts that schema theory has had an enormous impact on instruction. The component nature of knowledge and the network structure of schema both have implications. Marshall points out that students will organize their knowledge, set goals, and apply their skills regardless of the instructional approach. The key question becomes whether instruction can be designed to enable student to create more effective schemas. Students do not know in advance what organizational structure best fits the incoming instruction. Teachers need to help students create the best memory organization, “preferably one that facili-

tates both the encoding and retrieval processes” (p.114).

Marshall (1995) states that many approaches fall short for schema formation. One approach is seen frequently at the elementary level and involves moving from the easier to the more difficult concepts. The issue here lies in the danger that there will not be enough time for the more difficult concepts. It also requires the instructor’s perception of what accounts for the easy and difficult topics and this may not be representative of student perception (p.117). Another common approach is to follow the outline of a given text. This approach relies heavily on the textbook publisher. Frequently, unrelated concepts are presented in sequence. The danger here is that students may be perceiving concepts to be related in the wrong ways. A student’s schema needs to be fostered with accurate connections, and there is danger in following a given text that the organization of the text will not create the optimal schema.

Marshall (1995) and Robins & Mayer (1993) also take issue with discovery learning to the point of excluding other modes of instruction. Robins and Mayer (1993) claim that classroom activities need to foster the desired schema and not be activity for the sake of activity. Marshall (1995) concludes “discovery learning seems best suited for strengthening and expanding schemas, not for initial creation of them” (p.118). There is power in demonstration; students can experience concepts first hand. On the other hand, there are advantages to being told the rules required for certain outcomes. For Marshall, student knowledge is likely enhanced with exploration and experimentation. However, it is most productive when students have the necessary prior knowledge.

Marshall (1995) asserts that much of present instructional practice is based on the work of Robert Gagne (p.114). Gagne asserts that learning new material relies on one’s prior knowledge (Gagne, 1973, p.165). A “learner acquires a new item of knowledge largely because he is able to integrate previously acquired principles into new principles, and he cannot do this unless he really knows these previously learned principles” (p.165). Gagne also asserts that it is important for the educator to break a desired piece of knowledge down into subordinate pieces. Mastery of the subordinate pieces of knowledge is necessary to ensure acquisition of superordinate knowledge (pp.160-161).

Marshall (1995) argues that this approach to instruction requires great skill and is rarely implemented well (pp.115-116). It is quite difficult to ensure that each skill is broken down into the necessary subtasks and that each subtask is taught in a manner that stu-
dents will experience its interconnected nature. Frequently, the connections between subtasks are rarely emphasized and the algorithms are perceived as more important than the concept. “Finally, the structure of the hierarchy itself is at odds with schema theory” (p.116). The learning hierarchy requires that the teacher take a top down approach in delineating subtasks and that the learning take a bottom up approach. Meanwhile, schema theory is based on a network organization, stressing the connections between the subtasks, not the subtasks themselves.

**Instruction for Schema Development**

There are many ways in which schema based instruction will look different from other modes of instruction (Marshall, 1995, p.113). The quantity of factual information is de-emphasized while the integration of facts is emphasized. Marshall (1995) concludes that factual information will develop as a schema develops, but it will not be the central focus of instruction (p.120). The creation of active problem solvers will also be a natural result of schema based instruction. The focus of instruction is on the ability to make plans and execute those plans. Assessment will center on a student’s ability to integrate and apply knowledge rather than passively reproduce information (p.120). Another difference is in the view that the instruction takes. Instead of students taking a bottom up approach to learning, there will be a top down approach where one sees the “big picture” (p.120). The focus will be on creating “meaningful chunks” of knowledge where the links between chunks are specifically stressed.

The four types of knowledge for schema formation aid in the creation of the goals for schema based instruction. First, instructors will introduce the main ideas on a topic (Marshall, 1995, p.121). By limiting the number of main ideas, students can take a little time to develop identification knowledge while feeling confident and comfortable. Next, instructors need to choose their examples carefully. “It is crucial to have good examples that will serve as the foundation of elaboration knowledge” (p.121). The next critical step is planning knowledge. Instructors need to model their planning knowledge. Students learn a great deal from watching and experiencing experts wrestle a problem. It takes a well of self-confidence and quality communication to share the mis-steps and wrong directions taken in solving a problem (p.121). It is here that students experience the power of quality planning knowledge and the importance of execution knowledge. This process also ensures that both planning and execution knowledge become a part of the student’s schema.

Recent research (Fuchs et al., 2004; Quilici & Mayer, 2002) has pointed directly to schema based instruction as a better way to enhance student learning. Quilici and Mayer (2002) sought to examine “how people learn to recognize appropriate similarities between word problems” (p.326). The researchers are quite careful in defining the terms used in their research. Structural awareness is “a sensitivity to the way the key concepts in a problem are related to one another to form a coherent structure” (p.326). Structural awareness is involved in abstracting concepts, organizing information into a problem model, and integrating the model with existing knowledge. This all depends on one’s schematic knowledge. The researchers state that one’s structural awareness is linked with having structure-based schemas (p.333). The research encompassed two studies. The initial study asked students at the beginning of an undergraduate introductory statistics course to sort 12 statistic story problems by type. No instruction was given as to type, and no organizational structure was suggested. Then, the students took the semester of introductory statistics. At the completion of the course, students are again asked to sort 12 statistics story problems by type. Again, no organization structure was suggested. The results of the two sorting sessions were compared. It was found that students were more likely to sort by structural features of the story problems at the completion of the course rather than at the beginning of the course. The main study sought to examine the effects of direct instruction on how to recognize structural features. In this study, four groups of 36 students were created. There was a control group that did not receive direct instruction, a schema aid group, an example aid group, and a group that received schema and example aids. The schema aid group and the both aids group were asked to read a schema training booklet and answer questions in regard to the material presented. The control group and the schema aid group were given a neutral set of example problems to work through. The example aid and both aids group were given structure-emphasizing examples to work through. Then, all students were asked to sort a set of problems. No organizational structure was suggested.

Quilici and Mayer (2002) found that the control group tended to sort based on surface characteristics while the example aid and schema aid groups were significantly more inclined to sort based on structural properties (p.337). This research has direct implications for classroom instruction. It suggests “that direct exposure to schema-training exercises and structure-emphasizing examples promotes structural schema construc-
tion” (p.339). Quilici and Mayer recognize that more research is needed in the area, but note that their results are strong evidence in support of schema based instruction.

Fuchs et al. (2004) assert that “the link between the development of schemas and problem solving, especially for young and low-performing students, awaits experimental demonstration” (p.635). The study used 24 third-grade classrooms with a total of 366 students. Three groups of eight classrooms were created. The first group was considered the control or contrast group. The second group was deemed the schema based instruction group while the third group was deemed the schema-based instruction plus sorting practice group. The control/contrast group received a general mathematics problem-solving unit. The schema-based instruction group received instruction geared toward the recognition of specific problem types and the importance of recognizing surface feature similarities. These two groups also received instruction about the concept of skill transfer where the mathematical skills used to solve one problem can transfer to another type of problem (p.637). Students in the schema-based instruction plus sorting practice were given additional practice sorting problems according to problem type. All students were given pre- and posttests on mathematical problem solving and a posttest on schema development.

Fuchs et al. (2004) found that the schema-based instruction groups demonstrated more growth in mathematical problem solving skill than the control group. Also, the schema-based instruction groups were better than the control group at sorting problems by type than the control group. Their research with third graders affirms a link between schema-based instruction and the development of schema for mathematical problem solving (p.645). The researchers also conclude that schema-based instruction “represents one approach for dramatically enhancing mathematical problem solving outcomes for third grade student across the achievement continuum” (p.646).

CONCLUSION

It is evident from the amount of effort taken to clearly define the term schema and from the amount of research done on the role of schema in mathematical problem solving, that one’s schema has a paramount place in one’s mathematical problem solving capacity. There exists a relationship between one’s schema and the ability to problem solve via analogy. There is evidence that experience with worked out examples fosters schema development. There is also evidence that schema development will be enhanced if both instruction and worked out examples stress the structural features of a problem. Since one of the goals of mathematics education is the development of mathematical problem solving, it is imperative to have a clear picture of the role of schema formation and development in relationship to mathematical problem solving (National Council of Teachers of Mathematics, 2000).

REFERENCES


2008 Annual Colloquium on Research in Mathematics and Science Education

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2. Use double spacing with one-inch margins.

3. For references, diagrams, etc. follow the style described in the Publication Manual of the American Psychological Association (APA), Fifth Edition.

4. Paper length must not exceed 30 pages, including pictures, tables, figures, and list of references.

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