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Dr. Regina M. Panasuk

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on Educational Research and Practice

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Editor
Dr. Regina M. Panasuk

Assistant Editor
Dr. Jeff Todd

Graduate School of Education—University of Massachusetts Lowell

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TABLE OF CONTENTS

Educational Resources

Qualifying Paper

The Annual Symposium Journal is published once a year in April.

Graphic Layout by Thais Gloor Design

CONTRIBUTORS

Carol Shestok has worked in Westford, Massachusetts for 25 of her 33 years in education: K-5 Science Coordinator, Mentor/New Teacher Induction and Living Lab Director. She is a National Board Certified Teacher, a Presidential Awardee, and adjunct at Fitchburg State University.

Kathleen McLaughlin has worked as an elementary educator for the past fourteen years. She has been a classroom teacher, a mathematics coach, and is now a content literacy teacher. Kate recently earned her doctorate in Mathematics and Science Education.

Gray Fitzsimons served as an historian with the National Park Service for twenty years working in the fields of labor history and the history of technology. He is currently completing his dissertation on urban school leadership and reform in the Progressive Era.

Kristina Scott has worked in special education for the past nine years. She has been an ABA therapist, resource room teacher, PDD teacher, MCAS-Alt training specialist, and now supervises student-teachers.

Elizabeth Often teaches Trigonometry and Pre-Calculus at Greater Lowell Regional Technical High School. She is a student in the Mathematics and Science Ed.D. program at the University of Massachusetts Lowell.

Cameron Brown is a doctoral student in the Mathematics and Science Education program at University of Massachusetts Lowell. He teaches chemistry at Hopedale Junior-Senior High School in Hopedale, Massachusetts.

Patrick Morasse is a high school mathematics teacher in Lowell. He earned engineering and mathematics degrees from the University of Massachusetts Lowell, then returned in 2011 as a doctoral student in the Mathematics and Science Education program.

Edward Tonelli first taught as an associate law professor before moving to high school mathematics and physics which he taught for 15 years. He enrolled at the University of Massachusetts Lowell in 2009, and is currently working on his dissertation proposal.

2014 Annual Symposium Journal Call for Papers

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 educational research and practice. Please use the following guidelines:

WHEN SUBMITTING A PAPER, PLEASE USE THE FOLLOWING GUIDELINES:

1 Submit an electronic version of the paper, an abstract, approximately 150 words, and a biographical sketch, about 30 words. All pictures and diagrams must be submitted as 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), Sixth Edition.
5. Paper must be submitted by December 1.
6. Authors will be notified about the status of their papers by January 15.
7. The Symposium is scheduled in April.

A RESEARCH PAPER MUST 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

The length of the paper length might be up to 30-40 pages, including pictures, tables, figures, and list of references.

A position paper for the **Educational Resources** section can be up to 20 pages. It must present new ideas and developments of major importance to practitioners working in the fields of mathematics and science education, language art and literacy education, and leadership and schooling. It must reflect a variety of research concerns within the fields and deal with didactical, methodological, and pedagogical issues.

An **abstract** for a **poster presentation** can be about 150-250 words; must outline the major ideas of the research study (proposed or completed), or a teacher education program.

SUBMIT PAPERS AND CORRESPONDENCE TO:

Regina M. Panasuk, Ph.D.
Professor of Mathematics Education
Graduate School of Education

University of Massachusetts Lowell
61 Wilder Street, O'Leary 5th Floor
Lowell, MA 01854

Phone: (978) 934-4616
Fax: (978) 934-3005
Regina_Panasuk@uml.edu

Teaching Students From Non-Majority Cultures

Carol Shestok
Westford Public Schools

ABSTRACT

This study explored perceptions of culturally responsive majority culture teachers who taught non-majority culture students. Each teacher participated in four one-hour interviews. Findings suggest the importance of non-traditional PD that encouraged participants to reflect on their experiences as well as formal PD that was differentiated and relevant to practice. Findings have the potential to inform the preparation of pre-service teachers and broaden the concept of professional development for in-service teachers.

More than ever before, public schools in the United States are serving students whose cultural backgrounds differ from that of their teachers (Venison, 2009). Currently, more than 40% of public school pupils are from ethnic/racial minority groups, whereas approximately 83% of their teachers are not (NCES, 2006). Nationwide, there is a shortage of majority culture teachers who are able to meet the needs of a growing population of non-majority culture students (Rubinstein-Avila, 2006;Ruiz-de-Velasco, Fix, & Clewell,2000). This presents special implications for a largely, homogeneous, White teaching force with majority cultural value systems and cultural norms that often differ from those of their students (Bennett, C. I., 1995; Howard, G., 2006; Howard, T., 2010; Ladson-Billings, 1994). Research has suggested this situation results in a cultural mismatch between teachers and students with consequences for student performance (Gollnick & Chinn, 2009). Without conscious awareness, many teachers' practices contain personal cultural biases and prejudices that may interfere with their ability to provide effective instruction (Banks & Banks, 2007).

Little research is available on the type of teacher preparation that positively influences teachers' practice with students whose cultural backgrounds differ from their own (i.e. Halvorsen et al., 2009; Langelier, 2009). This study endeavored to identify the PD experiences that teachers perceive as influencing their practice with students whose cultural backgrounds differ from their own to better meet the needs of these students (Loucks-Horsley, Love, Stiles, Mundry, & Hewson, 2003; Sleeter, 1992, 2001, 2005). Study results have implications for in-service PD as well as for pre-service teacher preparation.

STUDY QUESTIONS

The research question that guides this study is: What professional development experiences do majority culture elementary teachers perceive as positively influencing their practice with non-majority culture students whose cultural backgrounds are different from their own?

Subsidiary questions are:

- What professional development experiences, such as courses, workshops, and trainings influenced teachers' practice with students who have cultural backgrounds that differ from that of their teachers?
- Have the teachers engaged in any non-traditional professional development experiences such as home visits, informal teachers' in-passing hallway or playground chats, learning from students and parents, and festivals? (If so, which, if any, influenced their practice with students who have cultural backgrounds that differ from their own?)
- What personal and cultural background experiences influenced the teachers' practice with students whose cultural backgrounds differ from their own?

THEORETICAL FRAMEWORK

Three research areas form a theoretical framework for this study: Cultural Mismatch, Culturally Responsive Pedagogy, and Principles of Professional Development. Culturally Responsive Pedagogy is teaching that mitigates learning obstacles for non-majority culture students by lessening the mismatch between school and home cultures (Au, 2002; Delgado-Gaitán, 2006; Gay, 2000, 2010; Ladson-Billings, 1994, 1999, 2001). In the culturally responsive classroom, teachers: 1) acknowledge and build on the legitimacy of cultural heritages as legacies and approaches to learning, 2) build bridges between home and school experiences, teach students to know and value their own and others' cultural background, incorporate home cultural resources into all subjects and skills, include all students in all classes; no students are taken out of class, and 3) utilize effective parent/teacher communication

Culturally responsive teaching requires initial and ongoing professional development (PD) (Wei, Darling-Hammond, Andree, Richardson & Orphanos, 2009). In this study PD refers to the learning experiences by which majority culture teachers improve their practice to meet the needs of non-majority culture students. This PD includes traditional or formal learning experiences as well as non-traditional or informal learning experiences. Traditional PD is generally highly structured with a designated beginning and end and is sponsored by an institution usually in a formal course format (Marsik &Watkins, 1990). Non-traditional learning opportunities include personal interactions and experiences and take on various forms, and may include students teaching teachers, teacher to teacher informal chats such as those that might occur at recess time, parents teaching teachers, home visits, and community involvement (Boud et al., 1993; Reischmann, 1986). Both traditional and non-traditional PD take place over varying amounts of time, have a variety of formats, incorporate standards for teaching, and develop content knowledge (Wei et al., 2009), ideally taking into account the participants' prior knowledge, stage of professional growth, andragogy (Reischmann,1986; Snow-Renner & Lauer, 2005) and time for reflection (Marsick & Watkins, 2001).

The reflective component of PD promotes growth in cultural competence (Boud et al., 1993; González et al., 2005) and is thought to be necessary for teachers to make sense of their intercultural experiences (Wei et al., 2006). Researchers Reischmann (1986), Marsick and Watkins (2001) state that it is through reflection that largely unconscious experiences are triggered so they are able to be understood. It is this understanding of intercultural experiences that promotes cultural competence.

In framing PD, Sparks and Loucks-Horsley (1989, 1990) identified five basic effective PD models. While they each contain their own underlying assumptions, locus of control, and method of delivery, no one model alone is appropriate for framing PD in cultural responsive pedagogy. Some components or a combination of models may be necessary for this (Sleeter, 1992).

METHODOLOGY

I used a qualitative approach for this study. Yin and Campbell (2002) state this approach will "contribute to our knowledge of individual, group, organizational, social, political, and related phenomena" (p.1). I explored majority culture teachers' perceptions through in-depth interviews, which provided a way to understand their perceptions of PD that had influenced their teaching (Glesne, 1999; Seidman, 2006). I selected NVivo 8 to assist in organizing and analyzing my data. I analyzed data both deductively and inductively.

INSTRUMENTS

I developed an instrument based on the tenets of culturally responsive teaching outlined by Ladson-Billings (2001; 2009) to use to identify culturally responsive participants. I piloted the instrument with teachers, college instructors, and K-12 administrators who were members of my doctoral study group. I made adjustments to reflect their input, and then re-piloted. Examples of the checklist statements include items such as: "This teacher capitalizes on the learning and thinking the students bring from home; This teacher develops students' cultural competence; This teacher does not only embrace mainstream values but also the embraces the values of other cultures."

I also piloted the interview protocol with the doctoral study group. The protocol was designed to be implemented during four in-depth, 60-minute, one-on-one sessions. Session one included demographic questions and participant interpretations of culturally responsive pedagogy (e.g., Can you speak about your interpretation of culturally responsive pedagogy?). The second through fourth sessions began by revisiting and clarifying previous sessions then proceed with session questions. Session two explored the teacher's culturally responsive pedagogy PD experience (e.g., Could you talk about courses or workshops that have helped you prepare for work with children who are different from you culturally or socioeconomically?). Session three investigated the teacher's professional context (e.g., Could you speak about the ways you use your knowledge of cultural difference to implement instruction that meet the needs of your students?); and session four explored the teacher's practice of culturally responsive pedagogy (e.g., What do you see is the role of the teacher in the classroom?).

PROCEDURE

To find study participants, I met with university faculty from a northeastern Massachusetts university who regularly interact with supervising teachers in kindergarten to grade five, a grade range of my interest and experience. I reviewed the culturally responsive checklist with faculty, and based on the survey they identified 30 possible participants.

Since approximately 83% of the current teaching force is of the majority culture (Au, 2006; Landsman & Lewis, 2006), it is not surprising that all the teachers identified by faculty were from the majority culture. I made numerous attempts to contact the 30 possible participants. In the end, eight agreed to participate, 17 did not respond, and five declined, citing personal reasons. Perhaps some teachers were influenced by the current educational climate of accountability and consequences to nonperforming schools and the time commitment of four in-depth interviews. Nevertheless, this sample was sufficiently large to provide in-depth, rich, and valuable information (Johnson & Chistensen, 2004; Patton, 2002; Seidman, 2006).

Each interview was digitally audio-recorded and transcribed. Pseudonyms were used to protect confidentiality. I provided each participant with a $10.00 gift certificate to Barnes and Noble bookstore at the conclusion of each interview as a token of my appreciation for their participation. I sent transcriptions to each participant for review to verify accuracy of their intent and to allow them to comment further. All participants indicated that their transcripts were accurate and that they had no changes to make.

All eight participants taught in grades Kindergarten through five in various systems in the northeastern Massachusetts area. They represented themselves, rather than their specific schools or school systems. Seven of the eight participants were female; one was male. Six of the eight teach in urban settings. Participants varied in educational level, age, and years of teaching experience. Although they were all vetted as culturally responsive, development is a uniquely individual process. Later analysis suggested that these teachers were found to represent various points along the Cultural Competency Continuum (Lindsey, Roberts, CampbellJones, 2005).

FINDINGS

While all participants reported that they taught students whose cultural backgrounds differed from their own, not every participant reported formal PD experiences prepared them for culturally responsive pedagogy. Of the eight participants, five had no traditional PD experiences in this area as pre-service teachers. Of these five, two participants had varying degrees of in-service PD on cultural proficiency through their master's degree work. Three had no formal PD experiences specifically regarding cultural responsive pedagogy and three participants have been involved in a school-based cultural competency initiative. All eight participants were active in informal PD through various school-based or district-based committees that meet after school hours.

All participants indicated that they believed teachers' beliefs including biases and stereotypes, influence classroom practice. They further indicated that once attitude towards issues is acknowledged and understood, attitudinal changes can occur. When speaking about beliefs, it appeared that participants grew more culturally aware and accepting of difference because of their negative reaction to family verbal displays of biases and stereotypes during their childhood and even adulthood. This reflected the seminal work on prejudice of Gordon Allport (1954) that although one's family may influence one's beliefs and attitudes, these need not become one's personal beliefs and attitudes. Additionally, all reported that they were open-minded. They interpreted open-mindedness as an acceptance of difference, which they felt developed during their growing up years.

Data analysis revealed three major findings. The first finding suggests that participants perceived non-traditional PD experiences as very important for building cultural awareness and understanding for working with non-majority culture students. This necessitates a broader definition of PD that includes non-traditional and traditional experiences (Wei et al., 2006). The second finding was a common core of factors that contribute to a positive professional learning experience. The third finding, although it could be considered as a sub-finding of the importance on non-traditional PD, produced such powerful participant responses that it is considered as a separate finding. This was the power of reflection.

NON-TRADITIONAL PD

Non-traditional PD approaches include past and present life experience; informally learning from teachers, parents, and students; learning from community involvement; and learning from media resources. The participants' self-reports reflected the work of Reischman (1986), Callahan (1999), Bond et al. (1993) who found non-traditionl learning very powerful. Exempifying developing cultural competence through life experiences, Jule stated:

> You know my summer camp was a Lutheran camp which was different than my schooling and that was opening my eyes a little bit to things that they did, and I am thinking you cannot do this or you cannot worship this way. It was really cool to see something different kind of open my eyes. That not everybody looks like me and believes what I believe the way that I believe or the way that I was told to believe. That was very interesting even though I was young. That was probably the first time that I saw differences.

Paul's comments were also consistent with Allport's (1954) theory. He said that hearing his grandfather's intolerance through the years helped him to become open-minded and accepting. As Paul explained, "He [my grandfather] is straight off the boat from Ireland. I guess I could call him a bigot of some sorts, he….Not tolerant. Yeh, not very tolerant of other cultures or any diversity whatsoever."

At some point in their lives, each participant said he/she experienced a feeling of difference from those around them. Throughout the interviews, the participants clearly indicated that their personal and professional experiences with difference combined with time for reflection on these experiences were powerful influences on their sense of efficacy in teaching students whose cultural backgrounds differ from their own.

Donna provided this example:

> I told you that my great grandfather was born here. I mean, generations, we go back generations in this town. They opened up the world for us, I should say; and it wasn't about us. I told you how embarrassed I was sometimes that we were called 'townies,' and we weren't welcoming, and that upsets me sometimes. But somehow in our family, I was just so lucky to have been brought up with a world view.

Kate spoke of learning through media when this was combined with a time for reflection, “It dawned on me how I get most of my information is reading about it in the paper. One was this past weekend. There was this special article on young Indian women who have their rite of passage.” She went on to explain, “There were two instances that I thought of you…. One was this past weekend. There was the Sunday [paper], and there was a special article on culture. I feel like I overlooked this culture thing. Now that I am talking with you about it, it just was there. When something is on the forefront, you tend to pay more attention to it.”

Helen spoke of her non-traditional PD experience when a parent taught her about cultures other than her own and to avoid minsonceptions, through parents. She said;

> The boys [in the Italian families] were treated with much higher respect in the family. They were expected to get the education and the daughters were not as important. I had the older sister, but they really wanted me to focus on the younger brother.

Marta spoke of learning to be culturally sensitive by going into the community.

She said:

> The more I get from the community, and the more that I get on the background, I think, I bring a more sensitive approach to my classroom and kind of know better what is going on and seeing things from different perspectives. It gives you a wider vision.

INFLUENCED BY A COMMON CORE OF FACTORS

In concert with the research of Reischmann (1986), Snow-Renner and Lauer (2005), and Wei et al. (2009) who posited that PD must meet teachers needs and have practical application, the participants voiced the importance that differentiation and relevance to practice played in a traditional PD experience for developing cultural competence. Participants acknowledged that differentiating includes respect for the participants’ learning style, knowledge base, stage of PD, including stage of cultural competence, and personal time enhances the experience. Referring to importance of differentiation with learning styles in mind, Paul stated, I like lecture based to a certain extent, because I like to sit back and take in all the information.” In contrast, Berta stated, “ [Teacher collaboration] is much better than me sitting in a classroom having someone just preach to me; and I’m saying I already know all that; or I can’t use that in may classroom; that would never work.” In addition, relevance to practice was of utmost importance. Daniella said, “To have someone come up and say, ‘This is the theory behind it. This is how we do it. This is how it’s implemented in the classroom. This works for me or this might work for you.’”

THE POWER OF REFLECTION

All participants reported that reflection is a powerful non-traditional PD experience thus supporting research that suggests that reflection serves as a meaningful activity for developing culturally responsive pedagogy (Boud, Cohen, & Walker, 1993; T. C. Howard, 2003; Marsick & Watkins, 2001). The opportunity for reflection on their experiences through the interviews in this study presented a powerful learning experience. The participants’ perception of the connections between the interview process and reflection were all the more powerful because these were unsolicited and unintended outcomes of the research. The participants’ comments about the interview process were made in response to a question posed at the end of each interview session. The question was not about reflection. The question was "Is there anything you would like to add to our discussion today?" This was asked at the end of each session to elicit any further thoughts. They voiced the importance of reflection for making sense of their learning experiences and that the one-on-one interviews provided venues for reflective thinking. When the participants revisited their previous experiences through conversations and personal contemplation, they said they viewed their experiences in new ways that enabled them to use the experiences in positive ways with their non-majority culture students. Further, the participants self-reported the power reflection had in the growth of their beliefs and attitudinal changes that helped their practice.

Donna’s statement serves as an example of the power of reflection. She said,

> I just want to let you know, for the record, that coming and talking with you has given me an awful lot. Your questions were wonderful and thoughtful, and there were things that you brought up that I hadn’t thought about in a long time. It has given me more food for thought, and it has just kind of fit and dovetailed so beautifully with what I am doing in school now.

DISCUSSION

The findings of this study reflect the perceptions of like-minded teachers who were identified by a common checklist. Generalizations, if any, should be limited to school districts with teachers in similar situations (Denzin & Lincoln, 1994). The findings have implications for practitioners, policy makers, and researchers. Practitioners need to develop awareness that they are cultural beings in order to work effectively with students whose cultures differ from theirs. They need to understand that their own cultural backgrounds including biases and stereotypes influence their beliefs, and that knowing one’s self is the beginning of attitudinal changes. In addition, they need to know that their beliefs are further shaped by the personal and professional experiences the practitioners encounter. These collective experiences influence their interactions with students whose cultural backgrounds are different from their own because by understanding themselves, the teachers are better able to understand their students and the different places their students are culturally. Whether the teachers are consciously aware of this or not, informal learning experiences with an time to reflect can have a major influence on their understanding of how to work with students whose cultural background differ from their own.

Policy makers need to make adjustments in current PD policy to assist practitioners in incorporating culturally responsive pedagogy into their teaching. First and foremost, there needs to be a broadening of the concept of what PD is. Formal learning experiences would benefit from incorporating practical applications for greater carry over. Further, a paradigm shift needs to take place so that informal experiences can be recognized and included in teacher's professional plans. Policy makers need to realize that these experiences need to take place in an environment of respect with adequate amounts of time for learning, practicing, and reflecting.

Researchers could replicate this study with a larger group of participants and/or with participants from differing grade levels. Further, to inform the teachers' cultural competence levels along the cultural competency continuum, researchers should identify or develop a large scale universal cultural competence evaluation instrument which would help avoid frustration and regression for participants. In addition, researchers could work toward developing and piloting a specific professional develop model to meet the needs of majority culture teachers who teach students whose cultural backgrounds differ from their own. This, in turn, may lead to the development and piloting of a model of PD that reflects the findings of this study. Finally, the lessons learned from research in the area of PD for in-service teachers could be incorporated into teacher training programs so that the pre-service teachers' early experiences can reflect good practices in culturally responsive pedagogy as identified by current practitioners.

CONCLUSION

There is a growing body of research that conventional PD forms may not adequately prepare majority culture teachers to meet the needs of their non-majority culture students. However, research is lacking with regard to what prepares these teachers for cultural responsive teaching. My study addressed this gap by exploring what teacher perceived as helping them to develop cultural responsiveness.

Through a qualitative method using indepth one-on-one interviews with teachers vetted as culturally responsive, three findings emerged. One is that non-traditional PD is valuable for developing cultural competence. Two is that differentioation and relevance to practice is necessary for learning and implementation. Third, time for reflection is of great importance.

These findings have implicaions for practicioneers, policy makers and researchers. Practitioneers need to understand that their own cultural backgrounds influence their beliefs and these beliefs are further shaped by personal and professional experiences. Policy makers need to make adjustments in current professionald evelopment policy to assist practitioners in incorporating culturally responsive pedagogy into their teaching. Finally researchers could replicate this study on a larger scale to further inform teachers' understandings of becoming culturally proficient.

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Examining Perceptions of Elementary Mathematics Coaching

Kathleen A. McLaughlin
University of Massachusetts Lowell

ABSTRACT

Coaching has become an increasingly utilized professional development strategy to improve mathematics instruction at the elementary level. This paper identifies, describes, and compares teacher and coach perceptions of elementary mathematics coaching from one specific school site. Qualitative research design was employed. Four teachers, comprising a grade-level team at an urban elementary school in a mid-sized, culturally and linguistically diverse city in Massachusetts, participated in the study with the researcher, who was embedded as the mathematics coach. Collected data include teacher background surveys, three sets of semi-structured interviews conducted by an independent researcher, audiotapes of coaching sessions, coaching logs, and teacher artifacts. The prevalent theme of the study was the full implementation of the Common Core Standards and how the coaching model served as the primary professional development strategy. The teachers and the coach found several aspects of coaching to be effective, including unpacking new standards, collaboratively planning Common Core-aligned modules of study, incorporating new instructional strategies and manipulatives, collecting, reporting, and analyzing multiple sources of student data, and developing interventions for struggling students. Both the teachers and the coach reported similar limitations of the coaching model, including insufficient access to the coach and the potential for interpersonal distrust or conflict that could preclude a productive coach/teacher relationship. The coach perceived three effective aspects of coaching that the teachers did not report, including modeling professional reflection, access to cognitive theory, and advocating for teachers with school administration.

The current educational climate creates increased demands on elementary teachers in the area of mathematics. For the most part, elementary teachers are trained as generalists and may lack the deep mathematical content knowledge required of standards-based mathematics instruction. Concerns about student achievement in mathematics and the shift to the Common Core Standards (National Governors Association Center for Best Practices, Council of Chief State School Officers, 2010) magnify the need for effective professional development in the area of mathematics.

The implementation of the Common Core Mathematics Standards presents challenges to elementary teachers. One issue that affects implementation is that the elementary mathematics curriculum programs currently adopted in many districts do not fully align to the new standards and have been inadequately retrofitted in an attempt to relate their contents to the new standards, although the new standards are dramatically different from previous versions. Additionally, the mathematics content in these programs lacks the coherence called for by the Common Core standards and often does not provide teachers with accurate mathematics (Wu, 2011). In most cases, school districts and their elementary teachers rely on these mathematics programs as the basis for the overall sequence of topics and for daily lessons.

The reliance on commercially-available curriculum programs is a result of the fact that elementary teachers, in particular, may lack the skills to successfully teach mathematics. Teacher preparation programs in the United States can often focus on pedagogy rather than subject matter knowledge and as a result, many elementary teachers may not have the mathematical content knowledge required to improve mathematics instruction (National Council on Teacher Quality, 2008). Additionally, many elementary preservice and inservice teachers doubt their ability to teach mathematics effectively in a standards-based context (Smith, 1996), and those with limited content knowledge often have poor attitudes toward the discipline (Bibby, 2002; Quinn, 1997).

If a teacher does not have a detailed, in-depth understanding of mathematics, s/he may not be able to guide student thinking, manage class discourse, or assess student strategy use. Another issue may be a teacher's limited pedagogical content knowledge. If a teacher has limited pedagogical content knowledge, s/he may have difficulties identifying student confusion and will be inadequate in attempts to provide students with alternate representations of concepts (Shulman, 1986). These limitations in subject matter knowledge and pedagogical content knowledge may lead to weak self-efficacy in teachers that then feeds into a cycle that includes inadequate feelings, low confidence, decreased effort, and poor teaching performance (Guskey, 1988; Mulholland & Wallace, 2001; Sanders & Morris, 2000).

If elementary teachers do not have the prerequisite knowledge and skills to teach mathematics effectively, then they must be provided with the necessary supports to learn them. Research indicates that there are several models of professional development that might support teachers while they are working toward improving their subject matter knowledge and pedagogical knowledge, which in turn will increase their feelings of self-efficacy (Borko & Putnam, 1996; Guskey, 2003; Hill & Ball, 2004; Wong, 1997). One particular professional development strategy is coaching, which focuses on improving instruction by using mathematics content and pedagogy as vehicles for teacher reflection and goal setting (West & Staub, 2003). The findings regarding the impact of elementary mathematics coaches are preliminary at best, but some believe content coaching is a promising professional development model to improve instruction.

COACHING AS PROFESSIONAL DEVELOPMENT

Coaching is an increasingly utilized professional development strategy to improve elementary teachers' mathematical content knowledge and pedagogical content knowledge. Originally introduced by Joyce and Showers (1982) as a replication of athletic and business coaching models, instructional coaches provide support to teachers as they try novel instructional approaches in the context of their own classrooms. Loucks-Horsley, Love, Stiles, Mundry, and Hewson (2003) define coaching as a form of professional development, where a coach, in a one-on-one setting, supports a teacher in the teaching context to "enhance the knowledge, learning, and practice" of the teacher who is trying to incorporate new learning into classroom practice (p. 204). Coaching is used to teach specific instructional strategies to inservice teachers and provide feedback and support while the teacher uses those strategies in her daily work.

In practice, coaching activities are far more expansive than how Loucks-Horsley et al define coaching. Neufeld and Roper (2003) describe "coaching, at its best… is grounded in inquiry, collaborative, sustained, connected to and derived from teachers' work with their students, and tied explicitly to improving practice" (p. 3). Specific coaching models vary in many ways while remaining true to the collaborative, learning-oriented, reflective nature of coaching. The difference between models can usually be ascribed to specific characteristics, such as who serves as a coach or the focus of the coaching. Some models allow classroom teachers to coach each other through the implementation of new instructional strategies and to build a collaborative professional culture. Some of these models, such as Critical Friends (Costa & Kallick, 1993), allow for teachers of similar expertise levels to coach each other, while other models, such as peer coaching, call for the coach to be a colleague with expertise in the focus area (Showers & Joyce, 1996; Swafford, 1998). Other models call for the coach to team-teach with the classroom teacher rather than observe and provide feedback (Neubert & Bratton, 1987). Other models build onto these generic models with specified protocols for planning sessions, classroom observations, and reflection or debriefing sessions between the expert coach and the classroom teacher, such as cognitive coaching (Costa & Garmston, 1994) or content-focused coaching (West & Staub, 2003). All coaching models, regardless of name or structure, focus on collaboratively developing teachers as professionals in order to improve curriculum and instruction. Coaching can be effective professional development since collaboration is a key to school improvement (Chapman & Fullan, 2007; Elmore, 2000).

COACHING AS EFFECTIVE ADULT LEARNING

Effective professional development calls for a focus on adult learning theory, or andragogy. Knowles, Holton, and Swanson (2005) make assumptions about the adult learner that are relevant to the professional development of teachers. One assumption is that adult learners need to know why they need to learn something. They need to perceive a "discrepancy or gap between the competencies specified in the model and their present level of development" (p. 125). It is this learning need that develops readiness to learn for adult learners. Adult learners also need reflection time to analyze their beliefs and needs in order to open their minds to novel concepts or strategies. Adult learners must have autonomy and must take responsibility for their own decision-making. They resent impositions and being told what to do.

The assumptions identified by Knowles et al. (2005) inform the types of activities that are likely to produce adult learning. Learning opportunities for adults must consider the role of the real world context and the applicability of concepts to everyday life as important to orient the adult learner. Additionally, the role of the adult learner's experience plays a crucial role in the continued learning of the individual. Learning opportunities must be individualized to account for what the learner already knows and to identify learning strategies that are best utilized by the individual, such as discussions, simulations, case methods, or problem solving activities. Adult learners motivate themselves to learn through a variety of internal and external pressures. One primary motivator is finding success with the application of a newly learned concept. This success increases one's self-esteem and motivates the learner to increase one's knowledge base. It can also result in increased job satisfaction.

Coaching intends to promote the professional growth and the learning of teachers. The coaching model for the professional development of teachers is closely aligned to Knowles' process model of andragogy (Knowles et al., 2005). The coaching model calls for the learner to be an active participant and to create realistic expectations for learning. The coaching model requires a climate of trust, collaboration, support, and mutual respect. It calls for the learner and the coach to plan together, including identifying needs and defining objectives and goals. The coaching model calls for learning situations to be inquiry-based and rooted in real-life situations. Lastly, it encourages individuals to reflect on their progress toward their goals, accept feedback about their learning, and analyze their needs in order to create new goals.

In terms of improving mathematics instruction, it makes sense that mathematics coaching would be an effective strategy. Drawing from Vygotsky's theory of social learning (1978), a person learns within his/her zone of proximal development through interactions with a more-abled person. Assuming that a mathematics coach has specialization in the area of mathematics and mathematics education, the coach would serve as the more knowledgeable peer to provide instruction and scaffolding for the teacher, in order to learn the Common Core Mathematics Standards, the related mathematics content, teaching strategies, and how to use models and representations to facilitate student learning.

RESEARCH QUESTIONS

Coaching is employed by many districts as a form of professional development to improve mathematics instruction (National Mathematics Advisory Panel, 2008). The adoption and implementation of the Common Core Mathematics Standards has increased the supports that elementary teachers need to meet the content and curriculum demands required to further improve mathematics instruction. In light of these new demands, it is vital to ascertain which aspects of coaching are deemed most effective by elementary teachers and their coaches so that coaching activities can be prioritized.

Two of the research questions in this particular study focused on teacher and coach perceptions of effective mathematics coaching. This paper examines the following questions:

1. What specific aspects of the role of the mathematics coach are most effective as reported by the teachers?
2. What specific aspects of the role of the mathematics coach are most effective as reported by the mathematics coach?

METHODS

A case study methodology was used to collect data about the factors affecting elementary mathematics coaching in a particular context. The site, the coach, and the participating teachers were purposefully selected to ensure that an authentic and naturalistic inquiry was conducted (Lincoln & Guba, 1985). Four elementary teachers, comprising an entire grade-level team in one school, were purposefully selected to participate in the study. These teachers were selected from the 11 teachers from two schools who consented to participate. The teachers were chosen specifically because data from all of the team coaching sessions could also be collected, in addition to all of the data from individual coaching sessions. The collection of data from team and individual sessions led to a richer analysis of the coaching model as a whole.

Over six months, the teachers shared their perceptions of and dispositions towards the coaching model as they experienced it. These data came from a variety of sources, including semi-structured interviews, audiotapes and logs of coaching sessions, and artifacts. Each participant was interviewed individually at the commencement, midpoint, and end of the study and transcribed audiotapes of the interviews were created. All planned coaching sessions were audiotaped, resulting in extensive notes of the conversations and the interactions. Participants shared artifacts, such as lesson plans/resources, student work, data reports, and teacher notes.

Lists of codes were initially developed from the related literature on subject matter knowledge, pedagogical content knowledge, self-efficacy, data-driven instructional decision-making, and perceptions of effective coaching moves. The codes were continually refined throughout the study. Audiotapes, transcriptions, and/or coaching logs of all nine team meetings, 24 individual coaching sessions, and nine semi-structured interviews were pared down into units of data that were coded. The data were continuously compiled and analyzed to comprise themes.

LIMITATIONS

The case study methodology was critical when examining the nature of mathematics coaching and in delving into the relationships between the teachers and the mathematics coach, and their perceptions of such relationships. However, this methodology has its limitations. The results and conclusions of this study are not generalizable due to the small sample size and the specific context of the research site. It is up to the readers to decide if the conclusions are transferable to the school environments in which they are familiar. Another limitation is that the researcher was embedded in this study as the mathematics coach. The proximity of the researcher to the site was a benefit because of the ability to contextualize data, but it was also a limitation due to the bias the proximity brings. To limit bias as much as possible, an independent researcher from the same university conducted all interviews.

USE OF FIRST PERSON

Because the researcher of this study was embedded as the mathematics coach in this particular context, reporting the findings can be confusing. After consulting with the

American Psychological Association's Publication Manual (2009), I have made the decision to utilize the first person point of view to report and discuss the findings. APA style mandates clear, concise writing that avoids ambiguity (p. 69) and using the first person point of view will allow the reader to fully understand that when I use the first person, I will be referring to my simultaneous roles of mathematics coach and researcher. When I use the term "mathematics coach," I am referring to the generalized concept of a mathematics coach, separating it from my role in this specific context. Similarly, when I use the pronoun "we," I am referring to me in my role as the mathematics coach and the four teachers who participated in the study. The pronoun we will be used when describing group actions or shared perceptions.

DESCRIPTION OF THE SITE

The participating team of teachers works in an elementary school that is part of a public school district in a mid-sized, culturally and linguistically diverse city in Massachusetts. The district is identified as an underperforming district and is undergoing corrective action for continued low achievement for students in all subgroups as measured by state-mandated tests. The district has invested in various mathematics initiatives in order to improve instruction, including adopting TERC's *Investigations in Number, Data, and Space* (2008), developing district curriculum guides to align the program with the state standards, and employing and training coaches in Content Focused Coaching in mathematics (West & Staub, 2003).

The school is located in a middle-class, residential neighborhood and draws its students from the west side of the city. During the 2011-2012 school year, the school served about 500 students in kindergarten through grade 4. The school's student population is diverse, but is less diverse than the district as a whole. Of the enrolled students, 39% are white, 19% Hispanic, and 33% Asian. African-Americans comprise 5% of the overall population and roughly 3% are multi-racial. The school receives Title I funding and provides free or reduced school lunches to 66% of its population. Roughly 33% of the students primarily speak a language other than English at home and 26% of students demonstrate limited English proficiency. Special education services are provided to 15% of the student population and the services are provided in the general education setting and in self-contained classrooms that service students on the autism spectrum.

The school has made significant progress in improving student achievement in mathematics over the last five years. The school was in year two of restructuring, but for the last three years has made Annual Yearly Progress according to No Child Left Behind (NCLB) guidelines (NCLB, 2002). The school now has no status in terms of its NCLB accountability status. The student performance in mathematics is considered "moderate." The student growth percentile for the fourth graders in 2010 was at the 42nd percentile and in 2011 was at the 55th percentile, which means that in addition to moderate performance, the fourth graders also exhibit moderate growth between third and fourth grade as compared to peers throughout the state.

All of the school's teachers are considered highly qualified according to NCLB guidelines, and all of the teachers who participated in this study hold professional teaching licenses and master's degrees in education. The teachers regularly collaborate with each other, on vertical committees, on district-wide committees, and with administration. The teachers and the school's administration demonstrate a commitment to professional learning, including analyzing student data to set goals, collaboratively planning instruction, and learning new instructional strategies.

RATIONALE FOR SITE SELECTION

This site was selected purposefully for many reasons. In order to be fully embedded as a researcher in a school's coaching model, I chose to investigate the coaching model in which I worked. I had served as the mathematics coach at the school full-time for five years and the past two years, due to budget cuts, had been the math coach half-time at this school and another school in the district. Another specific reason for selecting the site was that at the root of a quality naturalistic inquiry is willingness of the participants to be open and authentic in dealing with the researcher (Lincoln & Guba, 1985). The faculty had consistently demonstrated a genuine willingness to make their teaching practices open to inquiry. Every classroom teacher participated in the district's version of action research, called Cycles of Inquiry. Each school had a vertical mathematics team whose purpose was to analyze data from district benchmarks and state-mandated tests to develop school-wide goals based on student need. Each grade level team developed a grade-level goal that stemmed from the school-wide goal and cooperatively researched instructional strategies and planned units of study to work toward their goal with my support. Teachers developed inquiry questions after analyzing student data to identify struggling students and continually examined student progress. This willingness to engage in inquiry and open dialogue about practice was vital to collecting data that were valid and reliable throughout the study.

Crucial to qualitative research is the research relationship built between the researcher and the participants. Because I, as the researcher, had served as the mathematics coach at the research site for many years, I had developed a strong rapport with the faculty. The relationships between the teachers and I had been professional and collegial, yet cordial. The focus on improving student learning through improving mathematics instruction had always been the center of the relationships. Another reason for selecting this site was that, because I was hired by the school's administration with the specific task of coaching elementary teachers and it was the sixth year that I had held the position, it allowed for an in-depth case study into how the coaching model impacted the coached teachers, rather than a case study on the process of implementing the coaching model, as recommended by Campbell (2007).

FINDINGS

This section reports the perceived effectiveness and limitations of various aspects of the coaching model and the teachers' perceptions of available professional development in the area of mathematics. Specifically, the teachers and I valued the coaching model's role as the primary resource for supporting teachers in implementing the Common Core Standards, including unpacking the standards, aligning the curriculum, and planning modules and lessons as a team. We also deemed collaboratively analyzing student data, especially those of struggling students, and interpreting the data to make instructional decisions to provide interventions to be highly effective aspects of mathematics coaching. We also reported that we thought we needed a liaison between the grade-level team, the school, other schools in the district, and the district's administration, and that the coach serves that role. Both the teachers and I reported similar limitations to the coaching model, including insufficient access to the coach who was now half-time due to budget cuts and the potential for inter-personal distrust or conflict that could preclude a productive coach/teacher relationship. I perceived three effective aspects of coaching that the teachers did not report, including modeling professional reflection, access to cognitive theory, and advocating for teachers with school administration.

PERCEPTIONS OF PD OPPORTUNITIES

The first initial interview question was focused on mathematics-related professional development opportunities. All four interviewed teachers stated that the district offers graduate courses through a state university's extended campus master's program. The teachers noted that only a few courses concern mathematics and most of those offerings from the district focus on grades three through eight, lacking in early childhood. Only two of the teachers described school-based professional development opportunities available to them (Teachers 1 and 2, Initial Interview). These two teachers listed the following specific school-based professional development activities: early release day sessions; grade-level common planning times; before-school or after-school meetings using grant monies; and the school's vertical mathematics team.

The teachers also noted that all of the school-based professional development time was not devoted just to mathematics and they perceived time for mathematics professional development as being in competition with time for literacy professional development. None of the teachers referred to mathematics coaching as a professional development opportunity, but did cite some of the roles that the mathematics coach performs, such as convening the vertical mathematics team meetings and analyzing school-wide data, as available professional development.

To emphasize, none of the interviewed teachers cited mathematics coaching as a professional development opportunity even though they received professional development points for teaching re-licensure at the end of every school year for their participation in mathematics coaching. Rather, they mostly identified professional development with graduate-level course work and perceived that the available course work was more focused on upper elementary and middle school mathematics. The teachers identified other professional development opportunities they attend, such as meetings and workshops, but they rarely viewed the collaborative work in analyzing mathematics data, planning curriculum or student intervention, or consulting with each other or the coach as professional development.

TEACHER, COACH, AND DISTRICT

Throughout the entire study, the teachers consistently stated that the coaching activities related to the full implementation of the Common Core Standards were extremely effective. The teachers frequently reported that their main curriculum resource, *Investigations*, did not meet the Common Core Standards and expressed continued concern and frustration about trying to align the curriculum to the new standards without adequate time to plan. The teachers expressed apprehension about implementing the Common Core Standards on an *ad hoc* basis. When asked about the most effective aspects of coaching in the final interviews, all of the teachers believed that aligning the curriculum to the new standards and the module planning activities were highly effective. One teacher noted that it was particularly helpful to have a coach as an integral part of "developing a math curriculum with us—I barely opened my *Investigations* books this year" (Teacher 3, Final Interview).

The teachers felt that an important role of a coach is to provide the link between what happens in their classrooms to what the district expects of them. The teachers believed the district's expectations were ultimately reflected in the district-created pre-tests, post-tests, and benchmark tests. However, because the district shifted from a program-based curriculum guide to a standards-based curriculum guide, the teachers were uncertain about whether they were teaching what they were supposed to be teaching and relied on me to help correlate their practice to district expectations.

> The coach is really the liaison between what's happening [at the district office] to and between the other schools to what we're doing, so we know if we're on target…I think [the coaching model] was a big help (Teacher 4, Final Interview).

It was important to the teachers that the district's administration understood the challenges of the transition year, and they felt that it was crucial that I communicate their questions, concerns and ideas to district-level personnel (Teachers 1 and 4, Final Interviews).

I noted that a vital, but often under-recognized aspect of the role is serving as the buffer between the district administration and the schools (Coach, Final Interview). I stated that because the entire mathematics curriculum was in a state of flux, the schools received large volumes of information from the district office that needed to be disseminated immediately to teachers. I sought to filter the information in ways that was organized and helpful prior to giving it to the teachers. I tried to help them make sense of the district curriculum guides by unpacking standards and sequencing activities. When the district's Common Core committee sent a large binder of instructional resources organized by standard, not by module, I made a copy for the team and tried to preview it prior to any module planning session so that the resources could be easily incorporated into the teachers' plans. I also tried to fill in the gaps when needed. For example, when the team needed word problems that addressed the various problem structures required of the new standards, I created corresponding anchor posters and student recording sheets to the teachers' specifications and added graphic organizers, like part-part-part-whole charts. I identified an important part of a coach's job is to listen to teachers' concerns about the curriculum and then both distill concerns into actionable steps to facilitate implementation and also communicate those issues to district-level personnel.

I also saw value in imparting a vertical perspective of the pre-kindergarten to fourth grade continuum to the grade-level team of teachers. I sometimes found that the teachers often become "stuck in the grade-level box" (Coach, Final Interview). This manifested when the grade-level *Investigations* did not have lessons or activities to meet the new standards. Because I was familiar with other grade levels, I could introduce lessons or games from other grade levels to the teachers. I also found that the teachers sometimes perceived the Common Core Standards or other district expectations of students as "developmentally inappropriate" (Grade-Level Team Meetings 1, 3, and 7). I believed that offering a different theory of development was an effective coaching move (Coach, Final Interview). I explained that specific mathematics content is not developmentally appropriate or inappropriate. Rather, what makes something appropriate to learn is whether the learner has the prerequisite skills to which to connect the new concept and whether the learning activities have been sequenced appropriately so that the learner can continually build upon what s/he knows. I contended that convincing teachers to own this theory of development also helped them better unpack Common Core Standards and better plan modules. I also stated that I thought it helped teachers feel more accountable for struggling students because they stopped ascribing student difficulty to developmental inappropriateness (Coach, Final Interview).

I also reported my belief that I was an important liaison between the grade-level team and the school's administration. Often the teachers would bring up issues they encountered that were not directly mathematics-related in our consultations. For example, the teachers asked me to suggest that the principal make a master schedule change that involved a reading block so that they could extend their morning meetings to include more mathematics skills (Grade-Level Team Meeting 3). The teachers also asked me to seek clarification of the role of the English Language Learners tutor whom the principal assigned to their grade level during the mathematics block. An entire common planning block was devoted to ascertaining the needs of the students and the preferences of the teachers (Grade-Level Team Meeting 6). Following the meeting, I worked with the principal to create a new model of English Language Learner tutoring in mathematics and an accompanying schedule to accommodate the teachers' input.

In summary, the teachers saw me as a crucial link to district expectations and to what other schools in the district were doing to fully implement the Common Core Standards. I also recognized this critical link, but felt that my work in filtering and disseminating information from the district and my advocacy for teacher concerns was equally necessary to improving mathematics instruction. The teachers also valued my role as a liaison between their grade-level team and school leadership.

STUDENT DATA

The teachers and I consistently noted that my support in collecting, representing and analyzing student data was a helpful aspect of mathematics coaching. The data reports I prepared for each teacher using module post-test or district benchmark test data were deemed particularly helpful, specifically my incorporation of a color-coded format to indicate each student's level of mastery of a given standard as based on the test items (Teacher 1, Initial and Mid-Point Interviews; Teacher 3, Initial and Mid-Point Interviews). The teachers described how they used the data reports both to identify struggling students in their classrooms and also as a way to evaluate their teaching, such as if most of their class did well or poorly on a specific item or standard.

One area of concern for the teachers in using data was that they did not always value the test data (Teacher 4, All Interviews; Teacher 1, Mid-Point and Final Interviews). I responded to their concerns in a variety of ways. The post-tests for each module are mandated by the district. Each post-test has ten multiple-choice questions, two short answer items, and two open response items. The tests are read aloud to students in the primary grades so that the tests can assess their mathematics ability rather than their ability to decode text. The teachers consistently expressed concern that the multiple-choice items were often not valid because the children have difficulty remembering what each answer says. I responded to their concerns in two ways. One, I suggested that they have students cover the choices with a sticky note, and then solve the problem prior to finding which choice matches their solution (Grade-Level Team Meeting 5). Two, I relayed the teachers' concern to the district's mathematics coordinator who in consultation with the district's Common Core committee decided to limit the number of choices on multiple choice items to three (Coach, Final Interview). The teachers also continually expressed concern that the short answer and open response items yielded far more important data to inform their instruction. In turn, I advocated for short answer items on the benchmark test to replace some multiple-choice items and helped write the second benchmark test for the district (Coach, Final Interview). The teachers felt that it "was the best benchmark test ever" in part because they felt that their input was valued (Grade-Level Team Meeting 9).

Interpreting multiple sources of data as a team was a strength of the coaching model. In the final interview, I described efforts to help teachers evaluate student work. One example I cited was my inclusion of a criterion-based scoring rubric for each open response item on the post-tests to help teachers consistently score student work. I also recalled working with the teachers to look for patterns and trends in the benchmark and post-test data. I explained:

> The numbers alone don't help them identify next steps. The reports tell them if a student got something right or wrong. It doesn't tell you why they got it wrong and it certainly doesn't help you diagnose the presenting issues and suggest ways to intervene (Coach, Final Interview).

I thought that introducing the teachers to and modeling student interview protocols was a highly effective coaching role (Coaching Log 15). All four teachers cited how that helped them mine the data to posit theories about why students were struggling, including what prerequisite skills they might be lacking, and to devise instructional plans to intervene with the students (All Teachers, Mid-Point Interview; Teachers 1, 3, and 4, Final Interview). Together we used these analyses of data to plan intervention lessons that I would help the teachers deliver through in-class modeling.

IN-CLASS MODELING

In the mid-point and final interviews, all of the teachers and I stated that in-class modeling was a highly effective coaching move. However, we valued in-class modeling for different reasons. For the teachers, they valued the mathematics lessons that I modeled because it allowed them the opportunity to observe their students and learn more about them. One teacher explained:

> [The coach] modeled a lesson… and that was really helpful because we don't have that luxury to get to sit back and observe our students as much because we're so focused on everything… and to see the students that I might have missed. I can see where the language is really a barrier; whereas when they're with me all the time you get comfortable with them and you kind of miss it sometimes (Teacher 4, Mid-Point Interview).

Another reason that the teachers valued in-class modeling was it provided opportunities for me to work with the students. A result of in-class modeling was that I had a more holistic view of individual students, rather than just the quantitative perspective derived from reading test data reports. For example, one teacher noted that when we looked at data together after in-class modeling, it was like I had a "different feel" for the students (Teacher 1, Mid-Point Interview). The teacher perceived that I understood more about the children, such as attention issues or visual perception issues, which led to a richer analysis of data. I, too, believed that knowing and teaching the students was a vital activity. I believed it legitimized me as a capable teacher in the eyes of my colleagues and it allowed me to triangulate from multiple sources of data, such as test data, teacher anecdotal notes and student work, to better plan instruction to meet the needs of the students. I noted that in the debriefing after the lesson, each teacher individually articulated the same thing—that when I am teaching the lesson, they can really focus on the student learning and how the students interpret what is being said, the strategies that they employ, and their work habits. When they are teaching lessons, they have to focus on the delivery of the lesson and therefore, their observations of students are through a different lens (Coach, Final Interview).

My view of in-class modeling evolved throughout the study. Initially, I thought modeling was a poor use of time. I had modeled lessons for each of these teachers in previous years and felt that the teachers were proficient with the district's lesson structure and their grade-level's *Investigations*. During the course of the study I came to view modeling as one vehicle for accessing their classrooms and as a way to specifically integrate a new instructional strategy or a new tool. For example, I modeled using the new presentation stations (LCD projectors and document cameras) to help teachers integrate technology seamlessly in a math lesson. I often modeled how to use new manipulatives for teachers and students, specifically the Digi-Blocks that model the Base Ten system and the number balance to model equivalence. For me, the in-class modeling was important because it provided both teachers and students across the grade level with a common understanding of how to use the new materials and it ensured that the new manipulatives were integrated into the curriculum.

In addition to the integration of new tools, I believed in-class modeling was an effective strategy for improving differentiated instruction for students. I noticed that the teachers identified the language that I used or the questions that I asked students which they perceived as different from their own. Teachers would often note it right in the context of the lesson. One teacher asked directly, "Is that how you want me to say it?" (Coaching Log 6). This also held true for the representations that I employed to capture student strategies for solving story problems or other addition and subtraction calculations (Coaching Logs 11, 12, 13, and 14). Once modeled, the teachers and their students were able to use the representations to effectively share their thinking in a clear and accurate way.

LIMITATIONS OF THE COACHING MODEL

The teachers reported my availability as a limitation of the coaching model. When I was full-time in the building, they valued the dedicated mathematics intervention time I spent daily with the grade level (Teacher 1, Initial Interview). When the position was cut to half-time due to district budget cuts, their access to me changed. Being primary grade teachers, they thought that they needed to cede their coaching time to the upper elementary grades that must take the state tests. The teachers clearly perceived that those grades should receive more support because of the additional accountability (Teacher 4, Final Interview). The teachers also recognized that I was responsible for working with nine other grade-level teams. One teacher explained, "I know her time is limited and there are a lot of us that I'm sure have questions just like we've had" (Teacher 2, Final Interview).

The teachers explained that they would utilize mathematics coaching services more if I were full-time. One teacher stated that she does not "always use the coach as much as I should" because she does not want to be "too dependent" and because she knows "the coach is really busy" (Teacher 4, Final Interview). Teachers also noted that they would be far more likely to ask me to model more in their classrooms if I was in the school more often (Teachers 1 and 2, Final Interview). It was also evident that the teachers did not ask for the support that they ideally wanted. Rather, they prioritized their needs prior to requesting my services. One teacher explained, "I'd definitely be more apt to ask her if I didn't feel like I was going to step into her time that she needs to be helping someone else" (Teacher 2, Final Interview). I expressed the same limitations of the coaching model, especially when trying to fully implement the Common Core Standards. I posited that coaching was the only professional development opportunity offered to my colleagues regarding the new standards and believed that it was an extremely difficult task to do well in a part-time position.

Lastly, the teachers described a "really nice working relationship" with me where they can "say or ask her anything" (Teachers 1 and 4, Final Interview). However, they noted that the coaching model can only be "a huge benefit to children and teachers" if "you are willing to use it. I think you have to be willing to put yourself out there" (Teacher 4, Final Interview). Both the teachers and I reported that we were willing to openly reflect on our practices and trusted each other, but we recognized that in other cases the absence of those attributes would be a limitation of the coaching model.

DISCUSSION AND CONCLUSION

TEACHER PERCEPTIONS OF PD AND COACHING

Effective professional development requires teachers to engage in and reflect on activities that will ultimately improve their teaching practice, all while addressing their adult learning needs. Knowles et al. (2005) theorize that effective adult learning activities, including those as professional development for teachers, must be grounded in the real world, be directly applicable to their practice, and must connect to the learners' goals and experiences. Loucks-Horsley et al. (2003) further state that all mathematics professional development opportunities must attend to teacher specific knowledge, namely subject matter and pedagogical content knowledge. Elmore (2000) states that professional development is a core feature of school improvement and as a result, must address school-wide needs and objectives. Although the teacher change model of professional development is over a decade old (Guskey, 2003) and is widely implemented by educational administrators and staff developers, it is evident that teachers do not recognize many of these job-embedded opportunities as professional development.

The evidence in this particular study was clear. None of the interviewed teachers cited mathematics coaching as a professional development opportunity, even though most of the work with the coach is voluntary. When asked about the professional development opportunities available, they identified more traditional forms of professional development, such as graduate-level course work and inservice workshops. Although Elmore (2000) and Chapman and Fullan (2007) cite collaboration as the key to school improvement, the teachers in this context rarely viewed the collaborative work with each other and the mathematics coach, such as analyzing mathematics data, planning curriculum or student intervention, or consults with the coach as professional development.

Traditional forms of professional development, such as inservice workshops, can be considered a manifestation of the district and/or school priorities and thus, may not account for the adult learning needs as theorized by Knowles et al. (2005). However, coaching, as examined in this study, responds to the perceived needs of the teachers and continually provides support for teachers as they work toward their own teaching and learning goals. Even when faced with a mandate such as the shift to the Common Core Standards, coaching affords teachers a professional development opportunity that allows them to collaboratively learn, inquire, theorize, plan, and reflect on their own priorities and goals regarding the mandate. Even if teachers did not identify coaching as a professional development opportunity, other data collected in this study demonstrate that the mathematics coaching was indeed an effective form of professional development in terms of implementing the Common Core Mathematics Standards (McLaughlin, 2012). If teachers associate professional development as a way to learn the requirements of school, district, or state priorities, it may be a benefit that teachers do not perceive coaching as professional development. If teachers were to perceive coaching as a mandate, it could diminish some aspects of it that make it effective.

The disconnect between the school leaders' perception of professional development and the teachers' perception of professional development must be further studied and addressed. School districts allocate professional development funds for coaching to advance progress toward district goals, yet coaching seems effective because it incorporates the needs and priorities of the participating teachers, which may not fully align to the specific initiatives implemented in connection with the identified district goals.

PERCEPTIONS OF EFFECTIVE COACHING ROLES

Loucks-Horsley et al. (2003) define coaching as a professional development strategy that seeks to provide in-classroom support for a teacher who is employing something new she is learning. There are many different coaching protocols that require coaches and teachers to follow a prescribed cycle as outlined by the authors (Costa & Garmston, 1994; West & Staub, 2003). However, researchers have found the roles of coaches to be far more varied. Embedding professional development into the daily work of teachers requires coaches to demonstrate lessons, provide feedback following lessons, assist teachers with planning, introduce new strategies to teachers, convene meetings to discuss curriculum, instruction, and assessment, research and gather resources for teachers, analyze data and instruct teachers about how to use data, and teach teachers the content standards and the related content (Center for Collaborative Education, 2002; Neufeld & Roper, 2003; Poglinco et al., 2003). The actual role of a mathematics coach is so varied and so vast that the position can become unmanageable.

There were various roles of the coaching model that both the teachers and the coach perceived as effective. Specifically, they valued the coaching model's role as the primary resource for supporting teachers in implementing the Common Core Standards, including unpacking the standards, aligning the curriculum, and planning modules and lessons as a team. They also deemed collaboratively analyzing student data, especially those of struggling students, and interpreting the data to make instructional decisions to provide interventions to be highly effective aspects of mathematics coaching. They also reported that they valued the coach's role as liaison between the grade-level team, the school, other schools in the district, and the district's administration. Both the teachers and the coach reported similar limitations of the coaching model, including insufficient access to the coach and the potential for interpersonal distrust or conflict that could preclude a productive coach/teacher relationship. The coach perceived three effective aspects of coaching that the teachers did not report, including modeling professional reflection, access to cognitive theory, and advocating for teachers with school administration.

In trying to prioritize the various aspects of mathematics coaching, it is evident that the teachers want and need support. In the course of fully implementing the Common Core Mathematics Standards, the teachers did not prioritize the often-described formalized coaching cycle of pre-observation, lesson observation, and debriefing. The teachers were overwhelmed by a dramatic change in standards, and as a result, the curriculum. Teachers, in the context of the Common Core implementation, need mathematics coaches who have strong mathematics subject matter knowledge and pedagogical content knowledge to assist them in examining the mathematics of the new standards and have multiple ways to represent mathematical concepts. Teachers also need mathematics coaches who are highly skilled curriculum developers, since the commercially made mathematics programs do not meet the current need of elementary teachers. Lastly, teachers need a coach who is adept at analyzing data and diagnosing student difficulty. Elementary teachers are trained as generalists and need specialized support in developing appropriate student intervention and remediation lessons.

SUMMARY

The adoption and implementation of the Common Core Mathematics Standards increases the challenge of teaching mathematics for elementary teachers. Over the course of this study, the coaching model was employed as the primary professional development strategy for helping the teachers implement the Common Core Standards. The move to the new standards provided many opportunities for mathematics coaching to support the teachers as they read and unpacked the new standards, made mathematical connections between different standards, and learned the necessary new mathematics content. The coaching model also provided the team of teachers with support for planning modules of study, assessing student understanding and diagnosing student confusion, and increasing their pedagogical content knowledge to respond instructionally. The support of the coaching model throughout the full implementation of the Common Core resulted in improving the teachers' confidence to teach effectively in this new context. Elementary teachers, who are implementing new standards in more than one content area, will continue to need support from coaches who have specialization in mathematics content, curriculum, and pedagogy in order to improve mathematics instruction.

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Urban Superintendents and the Politics of School Reform: An Historical Case Study of Lowell, Massachusetts

Gray Fitzsimmons
University of Massachusetts Lowell

ABSTRACT

The challenge for contemporary urban school leaders of navigating through the political landscape while seeking to initiate and implement school reform has received a growing amount of attention over the past 25 years. Not only are superintendents subject to the competing demands of local interests, including those represented by local school boards and teachers' unions, but they are also increasingly constrained by state and federal mandates. This paper examines the historical roots of the contest between city superintendents and urban interest groups in the push to enact major school reforms. It highlights the major historical scholarship and understandings related to this topic and then explores, as a case study, Lowell's public school system, between the years 1900 and 1930, a period of major social and economic upheaval in the city, yet also a span of time during which professional school administration emerged both locally and nationally. Close attention will be given to the relationship between the superintendent and the school board, as well as the broader patterns in the contest over power and reform that prevail today.

Among historians of education, one of the most intensively examined topics over the past four decades has been the emergence, growth, accomplishments, and struggles of America's urban schools. Numerous dissertations, articles, and books on urban education have been produced, many of which focus, to varying degrees, on the superintendency (Donato & Lazerson, 2000). The majority of these historical works are case studies of individual urban districts. A few, however, explore the history of urban schools and school leaders in a national context. Despite the range of topics, locales, approaches, and perspectives encompassed in the history of urban schools virtually all scholars agree that it was during the period from about 1880 to 1920, when the "grammar of schooling" emerged, that is, when the modern school system that characterizes K-12 public education today developed and grew (Tyack & Tobin, 1994). That urban school districts were central to this development and expansion is a consensus similarly shared by all scholars. And, as historian David Tyack observes, the centralization of urban school management occurred between 1890 and 1920, a period in which school superintendents established themselves as the major administrative chiefs of school districts and formed enduring professional associations (Tyack, 1974).

With so much scholarship on the history of the urban school and urban school leadership it is reasonable to ask: What more can we learn from additional studies of this topic? One answer is, quite a bit, depending on the questions raised, the methods used, and the context within which the study is situated. With this in mind, this study focuses on the long-standing issue of power and control of the urban school. In general it examines the role of the superintendent in school change, namely in the shaping and implementation of school reforms, in the face of strong interest group activity. More specifically, it is an historical case study of school leadership in Lowell, Massachusetts, spanning nearly 100 years, from the city's founding in ante-bellum America through the early 20th century. This was a period in Lowell and in other urban-manufacturing centers marked by a dramatic influx of immigrants, the emergence of a large working-class population, and a steadily rising middle class, but with growing disparities between the affluent and the poor. It was also a time that marked the growth of a public school system, serving a majority of children from various socio-economic and ethno-cultural backgrounds. Moreover, many believed that their schools served as the foremost public institution for inculcating children with the republican values of civic virtuousness, social order, and social harmony, while promoting individualism, hard work, and just reward. In short, schools were seen as a great social unifier and social leveler that could help resolve long-standing tensions between republican virtue and market-oriented commerce (Hogan, 1985).

Lowell offers a unique vantage point to examine the growth and change of urban schools, school leadership, and the politics of school reform, in relation to the larger social purpose of schooling in an industrializing and ethnically diversifying society because from its very inception it was a manufacturing center based on factory labor. At the same time its founders envisioned a socially and culturally cohesive community that prized republican ideals while fostering upward social mobility, thus avoiding the misery and dangerous unrest found in slum-ridden factory cities of Europe. Against this backdrop, this study looks closely at the role of school leaders in developing and reforming Lowell's public school system. It explores not only their particular socio-cultural history and the changing characteristics of school politics, but also the growth of some of the key interest groups that sought to influence school reform. The broader aim, however, is to use Lowell as a case study to revisit and, where appropriate, reaffirm or revise the findings in a number of the major historical studies centering on the professionalization of the urban superintendency, the changing character of school governance and educational politics, and the role of superintendents as agents of school reform.

THE RISE OF LOWELL'S SCHOOL COMMITTEE

When Lowell was founded in the 1820s, the ungraded district school prevailed throughout Massachusetts. As historian Carl Kaestle has shown, local control of these widely dispersed district schools, which often consisted of a single, locally appointed teacher who instructed students of all ages, while crowded into a one-room schoolhouse, proved very popular especially in rural areas. The many ardent supporters of localism believed that decisions over school location, teacher selection, curriculum, and expenditures on public education, were best left to the people residing within the environs of the individual district school (Kaestle, 1983). On the other hand, common school advocates, including members of Lowell's earliest school committees, pushed for the consolidation of district schools and greater centralization in school administration. This contest over local control versus centralized authority persisted from 1820s, (in 1827 the state legislature passed a law requiring all towns to form school committees) into the 1850s, when the last of the district schools were eliminated largely as a result of state actions by both the General Court (the state legislature) and the Massachusetts Board of Education (Martin, 1894).

Lowell's school committee was established in 1826, upon the town receiving a charter from the General Court. In its first decade the number of school committee members varied from five to seven with elections occurring yearly. Beginning in 1836 when the state granted Lowell its incorporation as a city, the school board was composed of six elected members, along with the mayor, who chaired the board, and the city's alderman. As before, the city held elections each year. From its inception Lowell's school committee members included men from one of a handful of occupations ranging from clergymen, businessmen, and lawyers, to newspaper editors and high-ranking textile mill managers. Most were in their early forties and all of them were members of Protestant churches. Moreover, without exception the overwhelming majority of school board members were from the same political party, namely Whigs, in the 1830s, followed by the short-lived, nativist American Party in the mid-1850s, and then, in the late 1850s, the Republican Party. With few exceptions this occupational and political composition of Lowell's school committee was a defining characteristic of the school board for nearly one-half century (see Appendix A).

In its early years, Lowell's school board, led by Anglican minister Theodore Edson, faced a number of challenges to its authority stemming from the long-standing district school system. At its founding Lowell had six district schools, each of which was a non-graded school with one teacher who instructed anywhere from 15 to 40 students. In addition to the school committee that was formed after the state granted Lowell a town charter, there was also the "District" or "Prudential Committee" composed of an elected representative from each of the six district schools. By a statute in 1826, the Prudential Committee was charged with keeping school houses in "good order," supplying fuel for heating the buildings, providing "all necessaries for the comfort of scholars," and furnishing the school committee "with such information" to aid in its duties. In addition, the Prudential Committee was authorized to "select and contract with a school master," although the school board, also often referred to as the "superintending school committee," had the authority to approve or reject each teacher selection (Gilman, 1888). This two-tiered organization of school governance for Massachusetts towns represented a compromise on the part of the state legislature to accommodate supporters of local district control, while promoting more centralized leadership over all of the schools.

In Lowell, the result of this arrangement was a series conflicts between the two committees. The first stemmed from a school board directive to introduce two primers, recently authored by school committee member Warren Colburn, into the district schools. (One was Colburn's textbook on arithmetic which soon became widely used throughout New England.) Believing that the books deviated too radically from existing instructional practice, some members of the Prudential Committee refused to comply and, as a result, only some of the district schools used Colburn's texts. A second battle ensued in 1827 when the school board deemed one of the district school teachers incompetent and ordered his removal. This action proved so unpopular and raised such a political stir that none of the school committee members was reelected the following year (Gilman, 1888, p. 88). It would prove to be the only time in the 19th century that Lowell's school committee experienced a complete turnover in a single year. An even more formidable confrontation occurred five years later, when the school committee sought to end district school control altogether by convincing the town's selectmen to fund the construction of two school buildings, thereby consolidating the smaller disparate schools scattered throughout the growing mill town. The committee also sought to establish partially graded schools in these new buildings (Bender, 1975). Despite opposition from some townsmen, including two prominent attorneys and one of the most powerful mill agents in Lowell, the school committee prevailed. With this question of control settled, Lowell would emerge as a major center supporting the common school movement and among its advocates were Lowell's leading textile factory managers (Katz, 1968).

Joseph Cronin has amply documented the rising power of local school boards in the control of urban public schools during the 19th century. States such as Massachusetts vested school committees with the authority to hire teachers, establish curriculum, purchase textbooks and supplies, and examine students. Cronin also notes that by the 1840s, the ward system of electing school board members was widely established for school governance in New England's cities (Cronin, 1973). Lowell's school board typified those in many cities throughout the region. Upon its incorporation as a city in 1836, Lowell's annually elected school board consisted of one member from each of the city's six wards. Each year the board organized a series of committees, with such titles as school buildings, teachers, textbooks, reports, accounts, and finances, and until the 1860s, when the city established a superintendent's position, these committees handled most of the administrative duties of the public schools. By law, however, all major recommendations of the committees were brought before the entire board for approval. Furthermore, the public schools were a department within the municipal government with the school committee being responsible to the mayor and city council for its actions (City of Lowell, 1894).

The roles and practices of Lowell's ward-based school board in the management of the public schools became well established by the 1840s when Lowell emerged as the second largest city in Massachusetts. Again, as was typical in other Bay State cities, each of Lowell's school board members provided administrative oversight for the schools in his particular ward. This oversight encompassed a range of responsibilities, from teacher hiring and firing, to school building location and construction, to parent's concerns over grade promotion or classroom discipline of their children. Although in most instances final decision-making occurred before the entire school board, individual board members were frequently able to respond to the particular needs of the residents in their respective wards. While many late-19th century reformers would claim this ward-based system was tarnished by excessive political patronage and corruption, its supporters viewed this urban form of school governance as strongly democratic and highly responsive to the demands of the people.

THE EMERGENCE OF THE SUPERINTENDENCY

The first school superintendent in a New England city was Nathan Bishop, a lawyer and tutor at Brown University, who was elected as school chief in Providence, Rhode Island, in 1839 (Gilland, 1935). But, in Lowell, as in most other antebellum Northern cities, the school committee continued to control all facets of school administration. In 1840, Springfield was the first city in the Massachusetts to appoint a school superintendent who was not a member of the school board, but this was a short-lived experiment lasting only two years. An important development in local supervision of the state's urban schools occurred in 1851 when Boston established the office of superintendent, hiring Providence's Nathan Bishop (Tyack, 1974). A few years later the Massachusetts General Court passed a series of laws in 1854, 1856, and 1860 that authorized cities and towns to appoint a superintendent of public schools, subject to renewal each year. In most locales, however, the majority of residents opposed the hiring of a school executive and continued to place the control of local schools in the hands of the elected school boards (Martin, 1894).

Lowell was no exception in this resistance to hiring a school chief. While the city council approved an ordinance in 1854 that permitted the school committee to appoint a superintendent, board members deferred making a selection to the incoming school board for the following year. This school committee, however, failed to act. Factoring into its reluctance to appoint a schoolman was confusion over the language in the statute, as well as disagreement over the funding source for the schoolman's salary. In addition, city council and school committee members undoubtedly recognized that public opinion was strongly divided over the creation of a superintendent's position. According to one early assessment, Lowell's voters were split along three lines. First, were supporters who believed that "an able efficient superintendent would ensure the higher success and usefulness of [Lowell's] public schools by exercising a more thorough supervision over them than any school committee." These supporters also maintained that "were there one responsible head, entrusted with an equal authority over all of the schools, and who understood the condition of them all, [the schools] could not fail to be brought up to one common standard of excellence." Second, was a group of opponents who claimed that the superintendency was "an experiment of doubtful utility" and "one involving unnecessary expense." A third oppositional group "denounced the measure as a one-man power" that would thwart the democratic control of the city's public schools (*Lowell Daily Journal and Courier*, May 12, 1858).

For nearly a decade those who opposed the hiring of a superintendent prevailed. Although in 1859, aided by the city's mayor and a powerful mill agent who served on the school committee, a local former school principal and businessman, George W. Shattuck, was appointed superintendent. But opposition remained so strong that a majority of voters approved a municipal referendum to eliminate the school chief's position. The school committee, which provided Shattuck with generally favorable reviews after his initial year in office, was prohibited from appointing another superintendent and Shattuck's duties were again assumed by committee members (*Thirty-Fifth Annual Report of the Lowell School Committee*, 1860; *Lowell Daily Journal and Courier*, March 8,1860). As in other urban centers in Massachusetts, Lowell was not unique in rejecting the superintendency for outside of Boston, only a handful of cities, most notably Worcester and Lawrence, employed a school executive (Massachusetts Board of Education, 1862). For most of the Commonwealth's 350 cities and towns, the school committee handled the major administrative duties.

Gradually, however, opposition to the superintendency faded. This was partly due to the recognition among many school committee members that the complexity of school administration attendant to the growing school and teacher population, along with the rising number of schools, required a full-time supervisor. In addition, local school boards found it increasingly difficult to provide the requisite oversight for enforcing a growing number of state education laws tied to such measures as compulsory schooling, teacher examinations and certification, student examinations, vaccinations of school children, adequate school supplies, and the physical quality of school buildings (Massachusetts Board of Education, 1860). By 1865 nine of the 15 cities in Massachusetts, including Lowell, had school superintendents.[1]

As David Tyack has noted, early superintendents were often "aristocrats of character" shaped not only by the dominant Anglo-Protestant culture, but also by "their own idealized self-conception" of their role as community and school leader. Their qualifications stemmed "not so much from professional training," but instead from their "church membership and a shared earnestness" (Tyack, 1976, p. 258). In the 19th century, with few exceptions, the ranks of superintendents were exclusively male (Blount, 1998) and the majority hailed from rural towns (Tyack, 1976). As shown in Table 1, the nine school superintendents in Massachusetts cities in 1867-1868 largely conform to the social and cultural backgrounds described by Tyack. Seven were from rural areas and all were Protestants, mostly either Congregationalists or Unitarians. While Tyack is correct in noting that superintendents from this period received no formal professional training for the position of school chief, this group of schoolmen was somewhat unusual in that all but one held a college degree. Moreover, the majority served as school teachers and administrators, prior to their appointments to the superintendency. Of the nine identified four were the first to be hired as school chiefs in their respective cities.

From the outset of the urban superintendency, the power of the school executive was constrained by the school committee as reflected in the various municipal ordinances that authorized the hiring of schoolmen. The ordinance drafted in Lowell, which was virtually identical to

Table 1
Urban Superintendents in Massachusetts, 1867-1868

Name	City	Year Born (Birthplace)	Years of Service	Religious Background	Educational Background	Occupation Prior to Superintendency
John D. Philbrick	Boston	1818 (Deerfield, NH)	1856-1878	Protestant	Dartmouth College	State Superintendent of Schools (CT)
Edwin B. Hale	Cambridge	1839 (Orford, NH)	1868-1873	Protestant	Dartmouth College	High School Principa
Daniel W. Stevens	Fall River	1820 (Marlborough, MA)	1865-1867	Protestant	Harvard College	Unitarian Minister
Gilbert E. Hood	Lawrence	1824 (Chelsea, VT)	1864-1877	Protestant	Dartmouth College	Lawyer
Abner H. Phipps	Lowell	1816 (Portsmouth, NH)	1864-1867	Protestant	Dartmouth College	School Superintendent (New Bedford)
Henry F. Harrington	New Bedford	1815 (Roxbury, MA)	1864-1887	Protestant	Harvard College	Unitarian Minister
Jonathan Kimball	Salem	1819 (Kingston, NH)	1865-1872	Protestant	High School Graduate	High School Teacher
Eli A. Hubbard	Springfield	1804 (Hinsdale, MA)	1865-1883	Protestant	Williams College	School Teacher
Albert P. Marble	Worcester	1836 (Vassalboro, ME)	1868-1893	Protestant	Colby College	Principal (Worcester Academy)

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[1] The Lowell school committee appointed a superintendent in 1859, but public opposition led to a municipal referendum to strike down the ordinance that permitted the hiring of a school chief. After only one year the city council eliminated the position.

those in other Massachusetts cities, including Boston, Worcester, and New Bedford, called for the school committee to appoint a superintendent each year or in the event of a vacancy. The superintendent was charged with “the care and supervision” of the schools “under the direction and control of said school committee.” That the school committee had full authority over the superintendent’s tenure and salary was abundantly clear. The ordinance stated that the school chief “shall be removable at the pleasure of the school committee” and also declared that the superintendent “shall receive such compensation as they [the school board members] may from time to time consider” (*Charter and Ordinances of the City of Lowell*, 1894, p. 142). This legally proscribed institutional arrangement had long-term implications in Lowell and many other cities for it left school administrators vulnerable to public pressure, most notably the more powerful interests in a particular locale, and created a high degree of professional insecurity among superintendents (Callahan, 1962, especially pp. 52-54).

Beginning in 1864, when Lowell’s school committee hired Abner H. Phipps as superintendent, and continuing with the next four school chiefs, each of the city’s school executives assiduously adhered to the school board’s directives. Especially Phipps, who was aware of the decade-long opposition of many Lowell voters to the superintendency, these schoolmen worked diligently in their administrative duties, but refrained from recommending any major changes to the school system. As Phipps observed in his first annual report, “the object I have endeavored to keep steadily in view has been to make myself thoroughly acquainted with the practical working of the common school system as existing in this city, in all its details, and varied relations—to ascertain its defects and excellencies, and to acquire such an intimate knowledge of everything relating to the schools as would enable me to direct my efforts wisely and efficiently to promote their best interests.” Phipps further maintained that he had not been “ambitious to create a sensation and give éclat to the office of Superintendent by recommending any radical changes.” Instead he claimed that he was “inclined rather to accept the existing condition of our schools,” with the aim of seeking school improvement “quietly and gradually” (*Second Annual Report of the Superintendent*, 1865, p. 12).

The role of the superintendent in the regular school board meetings tended to reinforce their subservience to committee members. Each of the schoolmen served as secretary to the board, for which they received additional compensation, and they dutifully recorded the proceedings of the meetings. Occasionally the board would ask a school chief to report on a particular issue, such as the condition of a school building or the usefulness of a textbook, or even possibly a teacher’s fitness for duty, but the superintendent had no authority to vote in rendering a final decision. Moreover, in all personnel decisions, whether it was for teachers or principals, the superintendent was allowed only to make recommendations and only if he was asked to do so. The decision to hire or fire was exclusively in the hands of the school board. There were, however, limits to the hiring authority of the school board. For example, it was not until the early 1900s that the school board was permitted to hire school janitors. Before that time, the city council controlled all custodial appointments. Likewise, financial decisions resided with the school board, with the superintendent occasionally called upon to provide data or offer advice. Here again, though, the school board was authorized to spend only the amount allocated by the city council and only on specific items that the council earmarked in the annual school budget. In Lowell, as in other Massachusetts cities, the municipal government’s financial control over the school board, which in turn held the reigns of fiscal power over the superintendent, remained in place until 1922.[2]

Despite the constraints placed on Lowell’s schoolmen, a number of them initiated modest reforms. Among the most notable occurred in 1883 when Charles Morrill recommended liberalizing the admission policy of the public high school. Like those in many other cities, Lowell’s public high school was a fairly exclusive institution. Up until the late-19th century only a small percentage of students were admitted to high schools and an even smaller percentage received high school diplomas (Labaree, 1988). Typically school boards administered high school admission examinations that covered a range of subjects and these boards established the threshold for passing grades in each of the tested subjects. In Lowell and in other industrializing urban areas, this process favored children from wealthy and middle-class families, the majority of which were native born and Protestant. (See Table 2, which shows the numbers of Lowell students attending primary, grammar, and high school for each decade between 1857 and 1897; and Tables 3 and 4, which show respectively the number of students admitted to the high school in 1862 and 1881, and compares the number of Irish-born parents of these students with those born collectively in the United States, the British Isles, and English Canada.) Beginning in the post-Civil War period Lowell residents, including many parents of school children, Catholic as well as Protestant, demanded that

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[2] That year the Massachusetts Supreme Judicial Court, in *Leonard v. City of Springfield School Committee*, removed this fiscal restriction on school committees, permitting them to spend funds on any area within the school system that it deemed necessary, provided that that it did not exceed the amount appropriated for the school district (Russo & Mawdsley, 2004, chap. 8, p. 34).

Table 2
Average Number of Students Attending Lowell's Primary, Grammar, and High Schools, 1857–1897

Year	Primary Schools	Grammar Schools	High School	Total No. of Students in the Primary, Grammar and High Schols	Percentage of Students Attending High School
1857*	2,753	1,996	272	5,021	5%
1867	3,028	1,708	213	4,949	4.3%
1877	2,789	2,098	293	5,180	5.7%
1887	3,085	2,987	367	6,439	5.7%
1897	4,264	4,620	708	9,592	7.4%

*In addition there were 429 students in the intermediate schools, which were predominately filled with children of Irish-born parents. This additional number of students in the intermediate schools is factored into the percent of students attending high school for 1857.

Table 3
Grammar School Students Admitted to Lowell High School, 1862

Grammar School	No. of Boys Admitted	No. of Girls Admitted	Total Admitted	No. of Parents with Nativity of US, English Canada and England	No. with Irish-Born Parents
Edson	5	19	24	23	1
Bartlett	9	9	18	18	0
Franklin	7	3	10	10	0
Mann	5	0	5	0	5
Moody	13	10	23	23	0
Green	1	6	7	7	0
Colburn	1	6	7	7	0
Varnum	7	8	15	15	0
Totals	48	71	109	103	6

(Source: *Lowell Daily Journal and Courier*, July 28, 1862)

Table 4
Grammar School Students Admitted to Lowell High School, 1881

No. of Boys Admitted	No. of Girls Admitted	No. of Boys of Irish-Born Parents	No. of Girls of Irish-Born Parents	Total No. Admitted	Percent of Students with Irish-Born Parents
91	84	14	10	175	14%

(Source: *Lowell Daily Courier*, July 6, 1881)

larger numbers of students be admitted to the high school.[3]

In the 1870s, while Morrill was serving as superintendent, Lowell's school board debated changes to high school admission policy, but it continued to adhere to the tradition of the entrance examination. In fact, it was among the school chief's duties to prepare each of these exams and Morrill worked diligently to create questions, reflecting some of the basic content taught in the city's grammar schools. On at least one occasion a school board member criticized him for preparing tests that were too easy (*Lowell Daily Courier*, July 8, 1880). In his 1883 annual report, however, Morrill recommended dispensing with the exam

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[3] A Massachusetts statute cited by the school committee stated that "every candidate for admission to the High School be at least 12 years of age and shall have a diploma of graduation from one of the Grammar Schools of this city." Furthermore, the school committee declared that unless this diploma was presented "within two months after the beginning of the school year," or if the student did not attend a Lowell grammar school, an entrance examination was required. This statute would appear to allow all Lowell students with grammar school diplomas to be admitted to the city's high school. In fact, the results of the grammar school examinations, prepared by the superintendent and held twice each year (in June and January), determined who gained entrance into the high school. A passing grade for each of the subjects tested, the threshold for which was established by the school committee, determined not only a student's ranking and eligibility to attend high school, but the test scores also determined which students received a grammar school diploma (*Rules of the School Committee*, 1878, pp. 33-34).

altogether. Pointing out that there was "strong feeling among friends of those who failed" the examination and underscoring that these same Lowell residents "claimed that a grammar school diploma ought to be considered as a sufficient certificate of qualification for admission into the high school," Morrill declared that "this criticism seems to be just." He then stated that because Lowell has graded schools, "promotion from the grammar to the high school should be as easy as promotion from the primary to the grammar schools" (*Twentieth Annual Report of the Superintendent*, 1884, pp. 58-59).

However popular Morrill's proposal was to parents of some of Lowell's school children, the school board was unwilling to make such a drastic change. Part of its reluctance was due to the physical limitations of the 43-year old high school building, which, in 1883, strained to accommodate the ten teachers and the nearly 330 students who attended the school each day (*Lowell Sun*, February 8, 1879; *Twentieth Annual Report of the Superintendent*, 1884, p. 86). But there were also school board members who held that dispensing with the entrance exam would overwhelm the high school with academically inferior students. Many also believed that students who failed to gain admission still had the opportunity to further their education in the city's evening schools.[4] In the short term, the school committee agreed to a compromise that continued the exams in the standard subject areas, but changed the examination schedule from a single test administered on one day, to a series of tests given throughout the year in the upper grade of the grammar schools (*Lowell Sun*, December 22, 1883). This alteration resulted in a steady rise in the number of students admitted to the high school beginning in 1884, the year that this change was instituted. Morrill, however, did not live to see this reform for he died in April of that year. It was not until the 1890s, after the completion of a new high school building, when promotion from the city's grammar schools largely ensured Lowell's students of a place in the high school.[5]

RISE OF PARTISAN SCHOOL POLITICS

Debate over liberalizing admission to the high school occurred during a time of growing political partisanship within the school committee and more broadly within the municipal government. In the past there had been sharp divides over such public school reforms as the strengthening of compulsory education, the establishment of a reform school, the hiring of truant officers, the appointment of a superintendent, the purchase and distribution of free textbooks, the need for stronger teacher qualifications and improved teacher hiring, and changes to the school curriculum. Discussions over reforms at school board meetings were occasionally spirited, but the tone generally remained formal, board members behaved courteously toward each other, and comprises were reached. The earnestness and polite demeanor at the regular board meetings was no doubt reinforced by members of the clergy who were typically elected each year to the school committee. But underlying this climate of collegiality was a shared set of values and beliefs in which the committeemen viewed public schools, alongside the church and the family, as the setting for gaining not only academic knowledge, but for socializing and instilling discipline and moral character in children who would soon enough join the ranks of a dynamic, challenge-laden, and often morally tenuous market-driven society. It was also a hallmark of Lowell's school committees that virtually all of its members hailed from the same political party. Whereas Whigs formed the majority prior to the Civil War, Republican rule dominated the school committee into the 1870s.

This political unity began to break down in the 1880s with the growing power of the Democratic Party not only Lowell, but in Massachusetts. Aiding the resurgent Democracy was the controversial and polarizing Lowell lawyer, Civil War General, and erstwhile Radical Republican Benjamin F. Butler, who in 1882 won the gubernatorial election and was just the second Democratic governor in Massachusetts since the early 1850s. As in other cities in the Commonwealth, Lowell's Democratic Party was led by a mix of Yankee business and professional men, a large number of Irish-born and Irish-American middle-class men, and, increasingly, workingmen. It was this coalition that voted into office, in the same year that Butler was elected governor, Lowell's first Irish-Catholic mayor, John J. Donovan, a product of Lowell's public schools. (Blewett, 1976, especially pp. 174-175). Two years later, the school committee, which now reflected the city's altered political landscape (see Appendix A), appointed as superintendent George H. Conley,

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[4] Periodically the school board discussed the purposes of the high school entrance examination and its role in preventing "inferior scholars" from gaining admission to the high school. See for example, a report on the school committee meeting in the *Lowell Daily Courier*, May 30, 1876. For the perspective of the long-time high school principal Charles C. Chase, who supported the continuation of the exams, see the *Lowell Daily Courier*, May 9, 1882.

[5] By 1899 the procedure for high school admission was based primarily on a student receiving a grammar school diploma. However, performance on grammar school examinations continued to factor into student selection to the high school. For example, of the 427 students who received grammar school diplomas, 406 were awarded certificates to attend the high school (*Thirty-Sixth Annual Report of the Superintendent*, 1900, p. 50).

who was also an Irish-American Catholic, to replace the deceased Charles Morrill.

During the three years that Conley served as superintendent, the school committee vote frequently cleaved along party or ethno-cultural lines. For example, in 1885 the committee on textbooks, at the urging of the several Catholic members on the school board, including *Lowell Sun* newspaper publisher John H. Harrington, as well as a young firebrand and aspiring lawyer, Daniel J. Donohue, considered replacing Berard's history of England, with Stone's text on English history. Berard's book, charged Harrington, offered a decidedly anti-Catholic, anti-Irish perspective, and he asked, with such a large Catholic population in Lowell, "Why should this board continue a textbook which is so odious for its misstatements, to the detriment of their religion and to a class of our citizens?" Harrington declared that retaining this text was a "disgrace" and then cited passages in which Berard disparaged the Roman Catholic Pope and characterized the Irish as a "wild" and unruly people. Harrington and Donohue were, however, represented in the minority report of school committee, in which they were joined by other Democrats (*Lowell Daily Courier*, September 29, 1885). Throughout the proceedings Conley remained quiet and only one Republican, Universalist minister Ransom Greene, the lone clergyman on the school board, offered mild support to Harrington. All of the other Republican board members, who were also all Protestants, adopted the majority report that voted to retain Berard's text in the short term, but agreed to replace it when funds became available.[6]

This widening political and ethno-cultural divide in school politics reflected to the changing ethnic composition of the city. Lowell, by 1905, contained about 40,000 foreign-born residents, or nearly half of its population. (When factoring into the ethno-cultural characteristics the children of foreign-born parents who were born in the United States, this contrast in Lowell becomes even more pronounced.) These foreign-born residents hailed from over 40 nations, with the largest populations emigrating from Ireland, French Canada, England, Scotland, and Greece. A large number of immigrants, the majority of which grew up in rural areas and villages, found work in the city's textile mills. Although the number of parochial schools increased, most of the city's children attended the public schools. In certain wards, these schools were heavily attended by children of a particular immigrant group, most notably French Canadians who lived in the neighborhood known as "Little Canada." Cultural differences, especially in languages, created challenges for Lowell's principals and classroom teachers, concerning not only academic instruction, but also in enforcing disciplinary measures, as well as school attendance, and the and issuing of work certificates (Kenngott, 1912).

The school superintendents and the school committee responded only slowly to these major demographic changes in Lowell. Throughout the late 19th and early 20th century, partisan politics, namely between the Protestant and middle-class-dominated Republican Party, on the one hand, and the largely Irish-Catholic Democratic Party, on the other, remained the principle arena in which school policies and reforms were contested. Noticeably absent in Lowell's school politics, unlike the school politics in other larger cities such as Chicago and San Francisco, were representatives of organized labor (Katznelson and Weir, 1985). Except for the building trades, labor unions in the Spindle City were exceedingly weak, with textile workers constituting the largest working class population in the city, but also possessing little in the way of worker organization. The political partisanship of the school committee occasionally expressed itself as representing the interests of working families—for example, in the establishment of a manual training school in the 1890s (*Twenty-Ninth Annual Report of the Superintendent*, 1892, pp. 47-56), as an alternative to the high school—but with rare exception candidates who won election to the school board continued to come from either the business community or the medical and legal professions (see Table 4, previous).

Despite claims of political partisanship that some maintained hindered the school board in the performance of its duties (*Sixty-Ninth Annual Report of the School Committee*, 1895, pp. 13-15), some reform measures were passed. The most important, which included the introduction of kindergartens, the establishment of the manual training school, and the hiring of teachers who graduated from teaching colleges (Normal Schools), were initiated by school board members. Often the superintendent helped gather data or worked with committees assigned to develop policies or new programs. Arthur K. Whitcomb, who was appointed superintendent in 1891, played this supportive role for the school committee, but also proved to be the key school official for implementing these reforms. Like his predecessors Whitcomb had not received professional training for the superintendency, beginning instead as a school teacher and then principal in a Lowell grammar school before serving as school chief (*Lowell Sun*, October 4, 1920). Whitcomb would become an important transitional figure as superin-

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[6] During this heated discussion, the vice chairman of the school committee, Republican John J. Pickman, read a letter from Republican mayor Edward Noyes, who cautioned the school board against spending money to replace Berard's text and thereby running the risk of exceeding the annual appropriation for the city's public schools.

tendent for his tenure spanned the years leading up to the most dramatic reform in Lowell's school governance, when in 1911, a new charter passed that changed electoral process for choosing the school board.

SCHOOLS AND THE POLITICS OF REFORM

As William Reese observes school board reform during the Progressive era was part of a larger movement of urban reforms directed primarily by businessmen and professionals. The reorganization of school boards, stemming most importantly from the elimination of ward-based, partisan political orientation and instituting instead non-partisan, at-large representation, Reese further notes, dramatically transformed urban school administration and control "for decades to come" (Reese, 1986, p. 113). According to Reese, the business and professional men who achieved these changes sought to run schools like a modern corporation, with school board members acting as a corporate board and delegating the running of public schools to a professional manager, namely the superintendent. Despite claims of non-partisan school governance, however, politics was never removed from the schools, but rather, as James Cibulka has pointed out, a new kind of politics emerged. In fact, the traditional political machine remained prominent in many cities, but an "interest group model of subgovernments" became increasingly prevalent in which coalitions, sometimes comprising the political machine and at other times in opposition to it, formed around particular issues that, in the case of public schools, shaped a range of school policies (Cibulka, 2001, p. 17). Important to this concept is the recognition that professional school administrators were not autonomous actors, but operated with restricted authority. At the same time, the most effective school leaders were not above politics, but instead maneuvered within or responded to interest group coalitions in the conduct of school policy and the implementation of reforms.

In Lowell a municipal reform movement emerged in the 1894 spearheaded by a coalition of temperance advocates, Protestant Republicans some of whom belonged to the nativist, anti-Catholic American Protective Association, and French Catholics. In an usual move, the school committee admitted to the public in its annual report of 1894 that political partisanship had occasionally crept into its deliberations, but its members proclaimed that "the best interests of the schools require that politics should be as far as possible eliminated from the School Board, that superior merit and priority should be in the selection of teachers, that there should not be any discrimination against a worthy candidate on account of religion or politics" (*Sixty-Ninth Annual Report of the School Committee*, 1895, p. 13). The result of the reform movement was the successful passage of a new charter that increased the number of wards from six to nine, which put an end to dead-locked votes in the municipal government (Blewett, 1976). For the school committee, this change altered the number of school board members from 12 to nine, with one member elected from each ward. Although Republicans believed this new charter would offer them a better chance of returning control of the city government to their party, Democrats continued to win the mayoral contests. The new charter also brought virtually no distinguishable change in the operation of the school committee. Even a proposal to expand the power of the school superintendent and extend the tenure of his appointment to three years was not carried through (*Sixty-Ninth Annual Report of the School Committee*, 1895).

A popular figure among school teachers and held in high regard by most members of the school committee, the affable Arthur Whitcomb continued as superintendent until 1912, shortly after the passage of another municipal reform initiative. This one, however, proved far more sweeping in altering the city's political structure. The ward system was abolished and candidates were chosen at-large and without party affiliation. Further, open primaries for all candidates were held in place of the older candidate selection by city committees of the respective political parties. Behind this initiative were leading figures in the city's board of trade, but this included not only a number of the city's key Republicans, but also several very prominent Democratic businessmen and the highly popular Democratic mayoral candidate for 1911.

The passage of this municipal reform in 1911 also signaled the growing importance of interest groups that were independent of the main political parties. This kind of change was occurring throughout the United States. As Elisabeth Clemens has observed the institutional character of American politics underwent a fundamental transformation during the Progressive era, including the breakdown of the traditional fiercely partisan political party system; the creation of alternative institutions for channeling political discontent and aspirations away from the traditional party system; and the mutual reshaping of these alternative political institutions and the older party system to form a new polity based less on political and more on interest group identity (Clemens, 1997). In Lowell these interest groups included not only the powerful Board of Trade, but also two markedly different organizations, the Lowell Trade Union Council and the Middlesex Women's Club. Of these three the most active in school politics was the Board of Trade and the Women's Club.

Formed in 1887, the Board of Trade in its first two decades focused primarily on improving business conditions in Lowell, maintaining low taxes, and promoting Lowell businesses through local advertising and regional publicity.

Occasionally, though, it ventured into school politics when, for example, it opposed the expansion of kindergartens claiming that they were an "extravagance" that the city could not afford (*Lowell Sun*, November 21, 1894). By the 1910s, however, the board of trade generally supported most school expansion plans, including the major addition to the Lowell High School. While Board of Trade members continued to profess their concern over "extravagant" municipal expenditures, business leaders were generally satisfied with the city's public schools, especially the high school and vocational programs that were closely aligned with the needs and values of the business community.

Among the major supporters of the Lowell's public schools was the Middlesex Women's Club, established in 1897, with most of its members being from middle class or quite affluent Lowell families. Led in its early years by Mary Hall, the women's club pushed for greater scholastic and physical education opportunities for girls, on the one hand, while also advocating for more and better classes in the domestic arts. Hall and the majority of members were Republicans, as well as strong supporters of female suffrage. While women had been given the right to vote for school committee members in Lowell in 1878, no females were elected on the school committee until 1921. And throughout the 1910s, the women's club worked to promote female candidates for the school board.

CONCLUSION: THE MODERN SUPERINTENDENCY

In 1912, the year after voters approved the new municipal charter, the newly elected school board officials, the number of which was reduced from nine ward-based members to five at-large members, replaced Arthur Whitcomb as superintendent with Hugh J. Molloy. Over the protest of the lone Republican member, John Jacob Rogers, who claimed Whitcomb's ouster was politically motivated, the former school chief, who had served 21 years, far longer than any other Lowell school executive, graciously accepted the decision. The 49-year-old Molloy quickly emerged as a fiercely independent-minded superintendent whose style, temperament, and training marked a significant departure from his predecessors as well as the majority of 19th-century school chiefs noted by Tyack (1976).

Born in Randolph, Massachusetts, in 1863, Molloy was from an Irish Catholic family of rather humble origins. His father emigrated from Ireland to the United States in the mid-1840s and settled in Randolph where he worked as a bootmaker. The Molloy family prized education, for two of the daughters became school teachers and Hugh, after attending the public schools and completing high school in Randolph, studied at Boston College, graduating there in 1883. Molloy then taught at several public schools in New Hampshire, served as principal of a school in Lawrence, Massachusetts, before receiving an appointment as mathematics instructor at the Lowell Normal School. At the time of his appointment as superintendent Molloy was a vice principal at the Normal School and had just completed a master's degree at St. Francis Xavier College. He taught many female students who graduated from the Normal School and became teachers in Lowell's public schools (*Lowell Sun*, March 17, 1933).

While at the Normal School, Molloy became very familiar with Lowell's public school system as well as the city's political landscape. He was known for his oratorical skills and, although his predecessor, Whitcomb, was involved with other school superintendents through the National Educational Association, Molloy's association with other school executives was quite extensive. From the outset of his serving as school chief, Molloy was respectful but rarely hesitated to confront school board members, whether they Republicans or Democrats, if he disagreed with them. Although Tyack (1974) categorized the early professional superintendents as being either "administrative progressives" (those who stressed business managerial practices in school administration and social efficiency involving testing, sorting, and tracking of students throughout their school career) or "pedagogical progressives" (those who emphasized a curriculum and teacher instruction based on the stages of a child's emotional and intellectual development), Molloy was a combination of these two. A strong advocate of vocational education and a firm believer in applying business principles to track finances and manage school expenditures, he also worked assiduously with teachers to improve curriculum in reading and writing for the youngest students. Molloy also gained a reputation of being extremely supportive of teachers and the need to maintain adequate teacher pay. He famously challenged a proposed teacher pay cut during the depths of the Great Depression in 1932, urging teachers to oppose this action (School and Society, 1932, p. 121). Among his best-known legacies was the introduction of junior high schools to Lowell in the 1920s. Although he planned to retire in June, 1933, Molloy died suddenly in the spring of that year. His tenure had been almost as long as Arthur Whitcomb's. But unlike Whitcomb or the city's earlier school chiefs, Molloy may be seen as the first professional superintendent in Lowell.

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APPENDIX A

Lowell's School Committee, 1840-1885

Lowell's School Committee, 1840

Name	Age	School Committee Affiliation	Political Party	Occupation
Elisha Huntington	42	Mayor and School Committee Chairman and Member *Ex-Officio*	Whig	Physician
Amos Blanchard	33	Member, Ward 1	Whig	Clergyman (Congregational)
Nathaniel Thurston	34	Member, Ward 2	Whig	Clergyman (Freewill Baptist)
Uzziah C. Burnap	56	Member, Ward 3	Whig	Clergyman (Presbyterian)
Elisha Fuller	44	Member, Ward 4	Whig	Lawyer
John O. Green	40	Member, Ward 5	Whig	Physician
Robert Means	43	Member, Ward 6	Whig	Cotton Mill Agent (Suffolk Mill)

Lowell's School Committee, 1845

Name	Age	School Committee Affiliation	Political Party	Occupation
Elisha Huntington	47	Mayor and School Committee Chairman and Member *Ex-Officio*	Whig	Physician
Abner H. Brown	29	Member, Ward 1	Whig	Physician
Steadman W. Hanks	33	Member, Ward 2	Whig	Clergyman (Congregational)
Alonzo A. Miner	31	Member, Ward 3	Democrat	Clergyman (Universalist)
Frederick Parker	29	Member, Ward 4	Whig	Lawyer
John O. Green	45	Member, Ward 5	Whig	Physician
John Wright	47	Member, Ward 6	Whig	Cotton Mill Agent (Suffolk Mill)

Lowell's School Committee, 1850

Name	Age	School Committee Affiliation	Political Party	Occupation
Josiah B. French	50	Mayor and School Committee Member *Ex-Officio*	Whig (Coalition)	Stage Coach Company Proprietor
Willard Child	53	Member, Ward 6, and Chairman	Whig	Clergyman (Congregational)
John Maynard	46	Member, Ward 1	Whig	Apothecarist
Joseph H. Towne	44	Member, Ward 2	Whig	Clergyman (Congregational)
Ephraim B. Patch	43	Member, Ward 3	Whig	Real Estate
Ithmar W. Beard	37	Member, Ward 4	Whig	Lawyer
John O. Green	50	Member, Ward 5	Whig	Physician
Willard Child	53	Member, Ward 6	Whig	Clergyman (Congregational)

Lowell's School Committee, 1855

Name	Age	School Committee Affiliation	Political Party	Occupation
Ambrose Lawrence	39	Mayor and School Committee Chairman and Member *Ex-Officio*	American	Dentist
William W. Sherman	40	Member, Ward 1	American	Paymaster, Lowell Machine Shop
Joseph Merrill	67	Member, Ward 2	Whig	Clergyman (Congregational)
Joshua Merrill	48	Member, Ward 3	American	Bookseller
John A. Knowles	55	Member, Ward 4	American	Lawyer
Worcester Eaton	52	Member, Ward 5	American	Provisions Dealer
William H. Brewster	44	Member, Ward 6	American	Clergyman (Wesleyan Methodist)

Lowell's School Committee, 1865

Name	Age	School Committee Affiliation	Political Party	Occupation
Joshua G. Peabody	56	Mayor and School Committee Chairman and Member *Ex-Officiis*	Republican	Manufacturer, (Doors, Sashes, Blinds)
George Ripley	40	Common Council President, School Committee Member *Ex-Officiis*	Republican	Manufacturer, (Cotton Batting)
Samuel W. Stickney	62	Vice Chairman and Member, Ward 2	Republican	Bank President
Abner J. Phipps		Secretary	?	School Superintendent
James W. B. Shaw	43	Member, Ward 1	Republican	Dry Goods Store
J. Oramel Peck	29	Member, Ward 1	Republican	Clergyman (Methodist Episcopal)
Joseph J. Judkins	48	Member, Ward 2	Democrat	Bookseller
Samuel W. Stickney	62	Member, Ward 2	Republican	Bank President
Joshua Merrill	58	Member, Ward 3	Republican	Bookseller
John F. Frye	28	Member, Ward 3	Republican	Lawyer
James J. Twiss	43	Member, Ward 4	Republican	Clergyman (Universalist)
Charles Kimball	53	Member, Ward 4	Republican	Sheriff
Chauncey L. Knapp	55	Member, Ward 5	Republican	Newspaper Publisher
George F. Warren	34	Member, Ward 5	Republican	Clergyman (Baptist)
Owen Street	50	Member, Ward 6	Republican	Clergyman (Congregational)
John A. Goodwin	41	Member, Ward 6	Republican	Postmaster and Treasurer, Horse RR

Lowell's School Committee, 1875				
Name	**Age**	**School Committee Affiliation**	**Political Party**	**Occupation**
Francis Jewett	44	Mayor and School Committee Chairman	Republican	Beef Dealer
Josiah G. Peabody	66	Vice Chairman and Member, Ward 5	Republican	Factory Owner (door sash blind factory)
Charles Morrill	56	Secretary	?	School Superintendent
John W. Smith	59	Member, Ward 1	Democrat	Overseer (Merrimack Mills)
James W. B. Shaw	53	Member, Ward 1	Republican	Business Owner (dry goods store)
George H. Pillsbury	32	Member, Ward 2	Republican	Physician
Cyrus H. Latham	51	Member, Ward 2		Factory Owner (wire works)
Ephraim B. Patch	67	Member, Ward 3	Republican	Real Estate Dealer and Auctioneer
George E. Pinkham	35	Member, Ward 3	Democrat	Physician
Charles Kimball	62	Member, Ward 4	Republican	Sheriff and Jailer
William H. Anderson	39	Member, Ward 4	Republican	Attorney
William G. Ward	41	Member, Ward 5	Republican	Dentist
George F. Lawton	28	Member, Ward 6	Republican	Law Student
Benjamin J. Williams	34	Member, Ward 6	Republican	Attorney

Lowell's School Committee, 1885				
Name	**Age**	**School Committee Affiliation**	**Political Party**	**Occupation**
Edward J. Noyes	44	Mayor and School Committee Chairman and Member *Ex-Officiis*	Republican	Street Railroad Superintendent
John J. Pickman	35	Vice Chairman and Member, Ward 6	Republican	Lawyer
George H. Conley	32	Secretary	?	School Superintendent
John A. Smith	35	Member, Ward 1	Democrat	Printer
Stephen J. Johnson	31	Member, Ward 1	Democrat	Physician
John H. Harrington	30	Member, Ward 2	Democrat	Newspaper Editor
Herbert P. Jefferson	29	Member, Ward 2	Republican	Physician
John J. Cluin	25	Member, Ward 3	Democrat	Jeweler
Daniel J. Donohue	24	Member, Ward 3	Democrat	Lawyer
Ransom A. Greene	37	Member, Ward 4	Republican	Clergyman (Universalist)
Fred Woodies	36	Member, Ward 4	Republican	Clerk in Machine Shop
John F. Lennon	25	Member, Ward 5	Democrat	Dentist
Andrew G. Swapp	25	Member, Ward 5	Republican	Clerk in Textile Mill
Charles H. Conant	41	Member, Ward 6	Republican	Lawyer
John J. Pickman	35	Member, Ward 6	Republican	Lawyer

(Sources: Lowell city directories; School Committee annual reports; and school committee election results from the *Lowell Courier*.)

Grades 4–6 General Educators' Autism Teaching Efficacy

Kristina Scott
University of Massachusetts Lowell

ABSTRACT

In 2012, one out of every 88 individuals is diagnosed on the autism spectrum. Reports over the last seven years have shown an average increase of 23% more students with autism being reported in the public school system each year. Many public schools are struggling with trying to educate their populations with autism. This pilot study examined the research question: What is the autism teaching efficacy of grade four through six general education teachers? The constructs for measuring teacher-efficacy consisted of knowledge of practices, implementation of practices, and comfort level of teaching in an inclusive educational environment. Twelve out of 40 general education teachers in one urban district in Massachusetts completed this electronic survey. Cronbach's alpha was .892. The factor analysis, using an un-rotated factor solution and no rotation, from this survey yielded 10 eigenvalues above one, with four major eigenvalues above 4.0. The factor loads led to these categorizations: teachers with high autism teaching efficacy, teachers with knowledge but no practice, teachers with low autism teaching efficacy, and teachers who attempted strategies but lacked a knowledge base.

AUTISM TEACHING EFFICACY

According to the fourth edition of the Diagnostic and Statistical Manual of Mental Disorders (DSM-IV), autism is defined as having "marked abnormal impaired development of social interactions and communication" (American Psychiatric Association, 2000, p. 70). The number of children being identified with autism is increasing (Lynn & Collet-Klingenberg, 2010). According to the Centers for Disease Control and Prevention (2012), the diagnosis of autism has had a substantial increase from the year 1980 to the year 2012. In 1980, four to five out of every 10,000 individuals were diagnosed with autism. In 2012, one out of every 88 individuals is diagnosed on the autism spectrum. Reports over the last seven years have shown an average increase of 23% more students with autism being reported in the public school system each year (Noland & Gabriels, 2004).

With this increase in identification there has been an increase in the amount of services that the public school provides for students with autism (Stephens, 2005). Autism was first included as a distinct disability category under the Individuals with Disabilities Act (IDEA) in 1997. Prior to 1997 autism fell into the classification of "other health impairment" (Coffey & Obringer, 2008). In one decade, from 1997 to 2007, there was a 1,008% increase in students eligible for special education services due to this diagnosis. In the 1999-2000 school year, 65,424 students in the United States were eligible for special education services due to an autism diagnosis. In the 2007-2008 school year 256,863 students with autism qualified for special education services. In subsequent years the number of students qualifying for special education services under the autism disability category has continued to increase (Data Accountability Center, 2012).

INCLUSIVE EDUCATIONAL PROGRAMMING

No Child Left Behind (NCLB), increases in autism identification, and the emphasis on teaching in the inclusion setting have increased the push for educating this population in the general education classroom setting (Stitchter, Randolph, Gage, & Schmnidt, 2007). NCLB has demanded that all children be held to the same high curriculum standards, and that teachers find a way to help all students achieve academic success. NCLB looks to hold states and schools more accountable for student progress by mandating annual tests to school age children (in grades three through eight and in high school) (McGuinn, 2006). The Individual's with Disabilities Education Act (IDEA) 2004 also ensures that special education students have legal protection and accountability through mandates that require all students be educated in the least restrictive environment and taught using research-based practices. IDEA defines research-based practice as applying systemic and objective procedures that have been reported as successful in peer reviewed journals. These journal articles need to consist of rigorous data analyses that measure programs' effectiveness, with validation through replication by different researchers in a variety of settings (U.S. Department of Education, 2010).

The research on how to best educate students with autism, however, is relatively new. This leaves the educational community with lots of questions about how to teach each individual student with autism so that he/she reaches his/her full potential. Educators are being asked to comply with IDEA 2004, but are often given little information about effective research-based practices. The confusion for professionals working with students diagnosed with autism is confounded because up until 2008 there was no agreed upon standard (used across multiple professional organizations) for identifying and classifying interventions as research-based. With little guidance in classifying educational methods many public schools are falling short on trying to educate their populations with autism (Odom, Collet-Klingenberg, Rogers, & Hatton, 2010).

Studies conducted by Hendricks (2011) and Hess, Morrier, Heflin, and Ivey (2008) surveyed special education teachers who work with students with autism asking them to self-report knowledge and implementation of effective teaching practices used with this population. In the Hess et al. (2008) study less than 33% of the teachers surveyed had knowledge of specific teaching practices used with the autistic population, and less than 10% of the research-based practices were being implemented in the classroom. Hendricks (2011) examined the knowledge and implementation of effective autism programming practices in special education teachers in Virginia. This study, that also utilized a self-reporting survey, found a low to intermediate level of effective autism programming knowledge and implementation in the public school classroom. The lowest scores in effective programming were found most often when asked the knowledge of developing sensory motor and social skills and how these skills were being targeted in the classroom environment (Hendricks, 2011).

With the background these studies provided, this study examined the research question: What is the autism teaching-efficacy of grade four through six general education teachers? This general question was looked at through how comfortable these general education teachers are in influencing learning and the educational environment for their students with autism. It was also looked at through their knowledge and implementation of teaching practices that are considered research-based practices for working with students with autism.

METHODS

In the spring of 2012 the researcher conducted a series of interviews with general education teachers in grades four through six questioning how they perceive the inclusion of students with autism in the general education setting. The interview questions looked at what these teachers identified as the challenges and benefits of inclusion, the resources available to them, and their educational preparation to meet the needs of students with autism. Interviews, through a phenomenological perspective, allowed for the meaning of participants' lived experiences as general education teachers in the mainstream classroom to be discovered. From the data received from these interviews a survey was created to examine the teacher-efficacy of grades four through six general education teachers working with students with autism. This survey asked general education teachers about the familiarity and implementation of twelve evidence-based practices used with students with autism.

The researcher had university professors familiar with survey research and autism studies review the survey for both content and construct validity. By checking the survey design and the clarity of questions the measurement error associated with the survey was minimized (Dillman, Smyth, & Christian, 2009).

The constructs for measuring teacher-efficacy consisted of knowledge of practices, implementation of practices, and comfort level of teaching in an inclusive educational environment. The researcher hypothesized that with more knowledge of research-based practices there would be an increase in implementation of the practices and that when these constructs were high, teacher-efficacy for working in an inclusive educational setting would also be high. The researcher also thought the reverse of this would be true, meaning that with a lack of knowledge in research-based practices there would be a decrease in implementation and this would lead to low teacher-efficacy scores. The researcher did question if perhaps some teachers implemented research-based strategies with this population but just did not know the terminology associated with the practice, and if this were the case more average scores in teacher efficacy were hypothesized to be the result.

Participants self-selected whether they desired to complete the survey or not. In this present study only twelve out of 40 general education teachers completed this survey. Posavac and Carey (2007) acknowledge that this could be a potential threat to internal validity because individuals that complete the survey may be very different than individuals that chose not to do so. Dillman et al. (2009) refer to this as non-response error.

PILOTING THE INSTRUMENT

This survey was sent out electronically to all general education teachers in grades four through six in one urban school district in Massachusetts. (This district was chosen because it was where the interview data for the qualitative-side of this study were obtained.) A list of the grade four through six general education teachers in this district was obtained through the district's public website. The researcher used this list to access the teacher's email addresses and then sent an email explaining the study and its importance. Two subsequent emails with similar content were sent to the respondents to encourage more teachers to participate in the survey. These were sent one week and two weeks after the initial email, respectively. Despite these three emails there were still only twelve individuals out of 40 potential participants that completed the survey. The timing of the survey near the Thanksgiving holiday and the close of the trimester grading may have been one of the factors contributing to this. The fact the survey was on an area that not many general educators felt comfortable or knowledgeable about, based on the surveys that were returned, may have been another factor contributing to the low return rate.

All of the emails that were sent provided a link to take the online survey through the site SurveyMonkey. By using an external link, in addition to the few demographic questions asked of participants, the anonymity and confidentiality of the participants could be ensured. The online survey contained a cover letter informing the study's participants that they were in the correct location and the purpose and importance of their input in this survey. The cover letter welcomed the grade four through six teachers, acknowledged the push for all students to be taught in an inclusive educational environment, and asked for them to give their feedback. It also acknowledged that if the participants were to complete the survey they were providing their consent for the researcher to use their opinions.

The survey, overall, was estimated to take approximately 10-15 minutes for participants to complete. Each question had instructions that indicated to participants how to correctly answer the question. The first question is a multiple response item asking about teachers' perceptions of teaching inclusion classes. The next question focuses on how many years teachers have taught in an inclusion classroom where a student with autism was included. Then after this question a matrix asking how much or little influence teachers feel they have in providing specific educational opportunities and learning for students with autism is included. The next questions use radio buttons to have teachers assess their comfort levels in regards to educating students with autism. After this, another matrix assessing teachers' familiarity or unfamiliarity with specific research-based practices for students with autism is positioned. Teachers' use of strategies with this population is the next matrix in this survey. After these questions demographic information from participants, in regards to their grade level, number of years teaching, and subject content area is sought. There were no follow-up procedures with any of the participants.

RESULTS

Cronbach's alpha (Table 1) was run on all non-demographic data to assess the internal reliability of the survey. It assessed how well the overall survey construct (autism teacher efficacy) was measured. Cronbach's alpha for this scale calculate at .892. This was for a total of 40 survey items and the alpha score obtained indicates that these survey items are highly inter-related and therefore the survey is consistent. The Cronbach's alpha for standardized item-scale correlation was found to be .873. This, again, suggests the survey has high internal consistency.

The factor analysis, using an un-rotated factor solution and no rotation, from this survey yielded 10 eigenvalues above one (Table 2 and Figure 1). The scree plot showed four major eigenvalues, which registered above 4.0. The next four factors registered above 2.0, and the final two factors registering above 1.0. All of the scores that had an

Table 1
Chronbach's Alpha

Chronbach's Alpha Standardized Items	Chronbach's Alpha Based on	N of Items
.892	.873	40

Table 2
Total Variance Explained

Component	Initial Eigenvalues		
	Total	% of Variance	Cumulative %
1	11.663	28.446	28.446
2	5.655	13.792	42.239
3	5.176	12.625	54.864
4	4.502	10.980	65.844
5	2.897	7.066	72.911
6	2.765	6.743	79.653
7	2.446	5.966	85.619
8	2.134	5.206	90.825
9	1.895	4.621	95.446
10	1.161	2.832	98.278

Extraction Method: Principal Component Analysis.

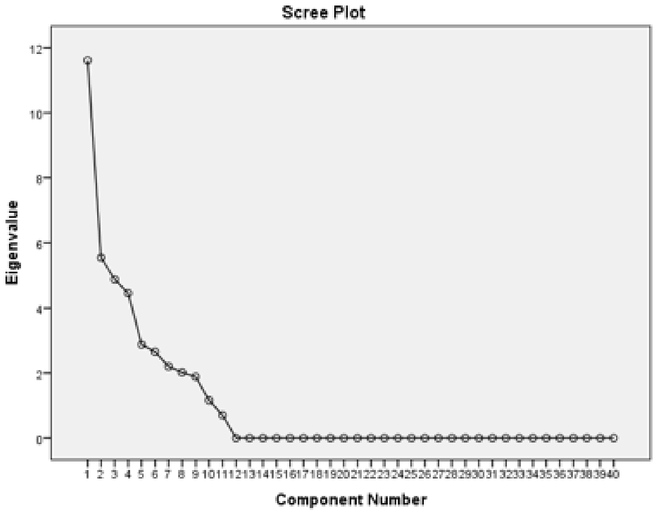

Figure 1. Scree Plot

eigenvalue of higher than 1.0 were examined to see if there was a latent variable that emerged from questions that aligned within these components. The questions that yielded components above 0.4 were inspected. After looking at all ten components the researcher decided to focus on the first four because these had the heaviest loads and more could be determined about the overall categorization of these factors.

The first component, with an eigenvalue of 11.66, showed that teachers who felt they were good at inclusion and meeting the needs of all their students felt that they could influence student learning, foster social independence, help in expanding social interactions, and could adapt the classroom learning environment to meet the needs of their students. These same teachers also had an increased familiarity with many of the educational strategies and practices used with students with autism. These strategies included: Boardmaker, errorless teaching, priming, chaining, contingency contracts, functional communication, generalization of skill sets, mands, modeling, and the use of peer tutoring. These same teachers were found to use gestural prompts, visual schedules, social scripts, and checklists multiple times during each day to keep students with autism engaged in the learning and on-task. These teachers would be classified as having high autism teacher efficacy because they felt they influenced the learning that occurred for the student with autism. Their high autism teacher efficacy may be due to their increased knowledge base and high frequency of implementation of these strategies within their classroom.

The next factor loading occurred at an eigenvalue of 5.66 and consisted of items that indicated that teachers felt that inclusion made them a better teacher and that inclusion was beneficial to some of the students. These teachers indicated that they were more familiar with applied behavior analysis, discrete trial training, and positive behavior support programming for students with autism. An indication of knowing these systems really well but none of the others may suggest that these teachers typically work with students with autism who are of lower cognitive abilities because all three of these program types focus on teaching concepts in small increments and through a very prescriptive method. This component also loaded for infrequent use of verbal and gestural prompts, but more frequent use of social scripts (which are typically visual representations of what to do in situations) that would make sense with a lower functioning group of students with autism. When students with autism are of lower cognitive ability teachers may feel that their room is beneficial and may be aware of the teaching done in their classroom, but usually this teaching falls on either an ABA therapist or a paraprofessional who may occupy a seat in the mainstream classroom.

Component three, with an eigenvalue of 5.18, was factor loaded for teachers who found inclusion challenging and not beneficial to students. These individuals were not comfortable fostering independence in students with autism and had extremely low knowledge of the research-based practices used for students with autism. Along with this there was an increase in the frequency of verbal and physical prompts given. The use of these types of prompts for a population that tends to be highly visual learners may be a less effective teaching strategy to employ.

The fourth component, with an eigenvalue of 4.50, found teachers that wish they were better at inclusion and struggle to teach all their students. These teachers acknowledged that despite this struggle they believe they have a high influence on what students with autism learn in the classroom, which include: keeping students on task, keeping students interested in learning, promoting positive social interactions, fostering social development, and the use of board maker

The majority of the participants in this survey indicated that they found inclusion to be challenging (92%), thought that it was only beneficial to some students (58%), and acknowledged that they, as teachers, struggled to teach all students (50%). From the same participant pool, 50% of the teachers wished they were better at teaching in the inclusion setting, 67% found inclusive teaching to be rewarding, and 42% acknowledged that being required to teach all students makes them a better teacher. In this survey only one of the twelve participants thought that inclusion was beneficial to all students.

Ninety-two percent of the teachers in this survey felt slightly or moderately comfortable adapting instruction for students with autism. Eighty-three percent also indicated they were slightly or moderately comfortable fostering independence with this population. When it came to managing problematic behaviors 75% of these teachers indicated they felt they had no control. These teachers, however, indicated that they felt more in control of helping students with autism develop socially by promoting positive peer interactions. All the participants except one indicated moderate or complete influence in the development of social behaviors. When it came to student academic learning and getting the students with autism engaged with the lesson 100% of the teachers rated their influence as slight or moderate.

The majority (82% or more) of teachers indicated they were either not familiar with or only slightly familiar with the research-based learning strategies for students with autism. The only exceptions to this were the use of token economy systems and positive behavior supports, which 30% and 50% of teachers respectively rated as moderately familiar with.

Although most of the survey participants indicated that they were not familiar with the evidence-based terminology most of the teachers were using strategies to aide in academic learning and on-task behavior in their classrooms. Ninety-two percent were using verbal prompts at least three to four times a day, with 42% using them more than five times a day. Eighty-three percent were using gestural prompts to the same extent. Seventy-five percent of these teachers indicated they were modeling their learning activities and providing structural checklists to accomplish these activities multiple times a day. Peer tutoring was also being used on a consistent basis by 75% of these teachers surveyed. These data indicate that teachers are helping to aid the student with autism in the general education setting. The success of these attempts, however, based on how teachers view their influence is questionable.

Based on the results of this pilot survey improvements can be made to hopefully attract more participants in a future study. There are some questions that did not load on any of the four major factors that can be discarded. This is proposed because the eigenvalues were relatively high and yielded meaningful constructs in this present study. Separating question one of this survey, which asks participants how they feel about inclusion, to multiple questions using a Likert scale is another change I would make. I would make this change because I do not know if participants checked all the answers that they believed to be true or just checked a few and then moved on to the next question. I would also look into changing the format of this survey to hopefully encourage more participation. I think if I gave this survey out in person, as a paper and-pencil survey, I may have received a better return rate.

FUTURE RESEARCH IDEAS

Since only twelve individuals responded to this survey the results for generalization purposes are questionable. In the future, I think I would get more results if I obtained access to multiple schools and had the backing of the district and principals to administer a hard copy of this survey to grades four through six teachers during a staff meeting. To make this study larger scale, I would go to multiple school sites and ask questions regarding the community demographics, school demographics, and set up of staffing in regards to autism so I could classify data that way. I would give myself approximately a semester to go to various schools and administer the surveys. I would then work on the data analysis of the survey for approximately another semester, looking at where the constructs fell and the relation of these questions more in-depth. If I were to conduct the study I just laid out my costs would include: gas to transport myself to and from each school, photocopying of paper, and time to make contact with multiple schools, get IRB approval for each school, set up travel times to each school, and transpose the survey responses from the hard copies to SPSS and begin analyzing.

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Can We View the Common Core Standards for Mathematical Practice As a Scientific Method?

Elizabeth Often
University of Massachusetts, Lowell

As an educator, I have become accustomed to seeing mathematics being separated or considered separately from science as a field of knowledge and of study. However, not everyone agrees with this view of mathematics, most notably Gauss, who called mathematics "the queen of the sciences" (cited in Taylor, 1998). Regardless of one's view of mathematics, either as one of the sciences or as a separate body of knowledge that provides substantial support for scientific research, it is reasonable to ask whether there is a method for mathematics analogous to the *scientific method*. In this paper, I will discuss whether the Standards for Mathematical Practice set forth in the Massachusetts 2011 Frameworks can be viewed as an analogy to the scientific method.

DEFINING A SCIENTIFIC METHOD

There is no single definition of the scientific method, but one can review the definitions of both science and the scientific method to arrive at a suitable definition. Fischer (1979) defines science as "the body of knowledge obtained by methods based upon observation" (p. 183). The statements that follow from this (according to Fischer) are of great value in determining what a scientific method is. Fischer notes that it is humans, rather than animals or computers, who are engaged in the practice of science. He further asserts that the authority in science is observation, but that this authority can be built upon, to form the scientific method(s). We can compare this with Kemeny's (cited in Fischer, 1979) description of the scientific method as a "cycle consisting of induction, deduction, verification, and an eternal search for improvement" (p. 186). Conant (1979) claims that there is no single scientific method that can be viewed as unifying all of the sciences. Rather, there are many different methods used by scientists in different fields.

Considering all of these viewpoints, I will define a scientific method as one which is a human endeavor, and which involves the following activities: observation, inductive reasoning (reasoning that uses specific observations to arrive at a general statement), deductive reasoning, and a process of verification or falsification. A hallmark of a scientific method must be a pursuit of accurate and appropriately detailed definitions and descriptions of phenomena. It is my opinion that these activities do not occur in a fixed series of steps, as Kemeny's (1979) use of the word "cycle" implies, but rather that all the activities are part of one process.

STANDARD FOR MATHEMATICAL PRACTICE

The Standards for Mathematical Practice (SMP) are a component of the *Common Core Curriculum for Mathematics*, and have been included in the *Massachusetts 2011 Frameworks for Mathematics*. The eight Standards for Mathematical Practice stand apart from the knowledge standards, and describe skills that students should be developing at all grade levels. The 2011 Frameworks document suggests that the Standards for Mathematical Practice are especially useful in conjunction with content standards featuring the word "understand" (Massachusetts DESE, 2011). This is likely because the Standards for Mathematical Practice describe the processes by which conjectures about mathematical objects are made, mathematical knowledge is demonstrated, and communications about mathematical objects and ideas takes place.

SMP AND SCIENTIFIC METHOD

The SMP consist of eight standards, which are described on pages 15 through 18 of the *Massachusetts 2011 Curriculum Framework for Mathematics*, but I will focus on how the language in six of them can be usefully compared with a scientific method. Rather than proceed standard by standard, I will refer to the definition I have offered for a scientific method, and show how the SMP reflects this definition. The language used in the first standard, that students will "make sense of problems and persevere in solving them," is an overarching statement that may also be used to describe a method used in scientific research. This standard can be dissected to determine which points of the definition I have offered it reflects.

Two of the standards, the first and the fifth, point to mathematics as a distinctly human endeavour, which I assert is one component of science and the scientific method. Standard I states that mathematically proficient students "make sense of problems and persevere in solving them" (p. 15), and Standard V states that such students will "use appropriate tools strategically" (p. 16). In the text of Standard V, some tools are listed, including straightedge, protractor, ruler, calculators and computer algebra systems. However, these tools are utilized as an aid in the solution of problems, or in the determination of patterns. Computers and calculators do not provide the answer to a problem any more than a ruler or protractor does. Rather, all of these tools may assist in collecting or testing data, and the student must be responsible for interpreting these data as part of his or her solution to a problem. The tools may enhance our ability to draw conclusions, make conjectures, and ask and interpret questions, but they are no replacement for these abilities.

A second component of the scientific method, observation, is addressed in three of the SMP, most notably Standard I, V, and VII. Standard I describes the approaches that can be taken to solving a mathematics problem, all of which involve observation. According to this standard, students will "analyze givens, constraints [and] relationships" (p. 15). Based on their level of cognitive development, students may manipulate variables, construct tables, draw diagrams, or use concrete items, such as algebra tiles or Cuisenaire rods in their solution of a problem. In order to solve a problem, the student must observe and record data and organize that data that might help to find a reasonable solution. One way that data may be obtained is through the use of appropriate tools, mentioned in Standard V. A straightedge and compass may be used to construct geometric figures, which can then be observed by the student (through measuring and comparing), and their qualities can be recorded. A calculator can be used to obtain various points on an equation of the type, $y = ax^2 + bx + c$, and the student may observe that the graph consistently has a similar shape. This observation of similarity is addressed in standard seven, "look for and make use of structure" (p. 16).

Once similarities or patterns have been observed, according to Standard VII, the student is encouraged to "make use of structure" (p. 16). Frequently, making use of structure would mean that students use inductive reasoning, but it may include deductive reasoning, as well. These two processes, induction and deduction, are important components of the scientific method. For example, a student investigating the shape of the graph of the equation, $y = ax^2 + bx + c$ may observe that the graphs always have the same shape, and conjecture (using inductive reasoning) that this is likely to be the shape of the graph of such an equation, no matter the values of a, b, and c. Once the student has learned the definition of parabola, and various means of expressing the equation of a quadratic function, he or she may use a deductive reasoning to verify the accuracy of a graph, or to find the maximum, minimum, or zeros of a function.

Standard III also addresses the inductive and deductive reasoning, critical to the scientific method, as students are asked to "construct viable arguments and critique the reasoning of others" (p. 15). The standard states that students will rely on "definitions and previously established results" (deductions) as well as "stated assumptions" and "conjectures" (p. 15). Additionally, it requires that students are able to determine flaws in logical reasoning, and bring those, along with counterexamples, to the construction of their critique of another student's argument. The scientific method often relies on inductive reasoning, but formal mathematics relies heavily on deduction. However, both inductive reasoning and deductive reasoning are used in mathematics, and both can be used as part of building a valid argument. Similar to the sciences, in mathematics students must defend their results and argue their conclusions using data and previously known facts.

The process of verification and falsification is also critical in the scientific method, and Standard III addresses how verification or falsification of conjectures could take place. Standards I and V also address the process of verification or falsification. Standard I, that describes how students "monitor and evaluate their progress and change course if necessary" (p. 15), is more general. Standard V addresses specific methods by which tools can be used to determine whether answers do or do not make sense. These methods include estimation and the use of specific technology such as calculators and spreadsheets, which can be utilized to check the validity of mathematical models.

Finally, standards III and VI both address the importance of accurate and complete definitions, which I have given as the final component of the scientific method. Standard III, as noted, requires students to be able to "construct viable arguments," that is, to communicate both effectively and with mathematical accuracy. In order for students to do this, they must know the definitions of various mathematical objects, and be able to describe them. This is part of a process, and is underscored by Standard VI, which states that students must "attend to precision" (p. 16). The precision referred here is not only precision in calculation, but mainly precision in language. Students must use the correct vocabulary, and be sure to describe situations, procedures and their reasoning clearly.

IS THE COMPARISON USEFUL?

While the Standards for Mathematical Process are specifically used for mathematics, they reflect the activities that make up the scientific method. There are multiple reasons for this. First, and perhaps most importantly, much of scientific research utilizes mathematics for data analysis. Therefore, it is important for both students and teachers to have an understanding of the process by which mathematical knowledge is developed and verified. Although it is possible for students to use formulas without knowing how they were derived, it is important that students not see mathematics as a discipline that is delivered, fully-formed, to the student. They must realize that there is a justification for the use of various formulas and definitions, and that they, too, can develop the ability to observe new patterns and develop new formulas and theorems.

Second, as has been stated previously, there are some differences between the construction and verification of mathematical knowledge and the construction of scientific knowledge. Because of a heavier reliance on observation and inductive reasoning, scientific knowledge is by necessity more tentative than mathematical knowledge. At the same time, the deductive nature of mathematics does not mean that mathematical knowledge is unchanging. Today's students may become the mathematicians who develop new methods of solution for problems, who devise new and more elegant proofs of theorems, or who develop mathematics that will support scientific findings. Through consistent use of the Standards for Mathematical Practice in classrooms, it is possible that teachers can help students develop skills that can be useful in both mathematics and science, skills that extend beyond content and that allow students to question authority, and to defend their own arguments. As C. P. Snow noted in *The Two Cultures*, scientists have this willingness, and thus they "have the future in their bones" (p. 10). By providing a process analogous to the scientific method, the Standards for Mathematical Practice will, I hope, provide the same for students of math.

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Inquiry-Based Learning: A Comparative Analysis of the Literature

Cameron Brown
University of Massachusetts Lowell

ABSTRACT

The College Board promotes the use of inquiry learning approaches in its revised Advanced Placement (AP) science courses (College Board, n.d.). This new emphasis on inquiry learning has caused a debate in the AP science teacher community regarding the efficacy of inquiry learning approaches. This current debate can be seen as a rekindling of the discourse on discovery learning that occurred in the 1960s. In an attempt to inform this current debate, this essay presents an analysis of Jerome Bruner's hypotheses related to discovery learning. Bruner's claim that discovery learning promotes the development of problem-solving ability, and improves student motivation and retention is evaluated based on the ideas of David Ausubel as well as empirical research.

A 2002 report by the National Research Council (NRC) entitled *Learning and Understanding* provided the impetus for the College Board's revision of its Advance Placement (AP) science courses (Koebler, 2011). In 2012 the new biology curriculum was offered for the first time. The new chemistry curriculum will be offered in 2013. Some of the changes seen in the redesigned chemistry curriculum include:

- A reduction in the number of concepts students need to learn
- A focus on scientific inquiry and student-directed labs
- A de-emphasis on the "lecture-demonstration model" (College Board, n.d.)

The new course expectations have ignited a contentious debate among AP chemistry teachers over the role of inquiry learning in science education. Some teachers opposing changes in the curriculum argue that inquiry learning approaches are highly inefficient and are not as effective as direct teaching (Dingle, 2012). Proponents of the new AP chemistry curriculum support greater inclusion of inquiry-based learning activities on the basis that these activities promote the development of high-level cognitive skills as well as greater retention (Males, 2012).

The debate occurring in the AP chemistry teacher community seems to be the latest front in the long-running argument over the merits of inquiry-based learning. A similar debate occurred in the 1960s. In this time period we find contrasting viewpoints in the writing of Jerome Bruner and David Ausubel. While Bruner did not use the term *inquiry learning* he is cited by many as the founder of *discovery learning*, which is seen by some as an equivalent approach to learning (de Jong, T. & van Joolingen, W., 1998; Kirschner, Sweller, & Clark, 2006). In this essay I provide an analysis of Bruner's ideas and hypotheses related to discovery learning. My analysis of these ideas is largely based on the writing of Ausubel as well as empirical research. I believe this analysis can help inform the current debate over the role of inquiry in science curricula that is occurring in the science teacher community.

BRUNER'S DISCOVERY LEARNING

For Bruner (1961) the goals of instruction were to aid students in learning about a subject as well as to help them become self-reliant thinkers and effective problem solvers (p. 23). Bruner (1977) recognized that the rapid accumulation of knowledge in the 20th century meant the goals of education needed to change. He suggested that education needed to teach fundamental principles and major themes (p. ix).

In discussions of the history of science the term discovery is often used to refer to obtaining new knowledge. Bruner (1961) indicated that discoveries can occur at the "frontier of knowledge or elsewhere" (p. 22). Bruner posited that "discovery, whether by a schoolboy going it on his own or by a scientist cultivating the growing edge of his field, is in its essence a matter of rearranging or transforming evidence in such a way that one is enabled to go beyond the evidence so reassembled to additional new insights" (p. 22). Therefore, he believed that discoveries could also occur in the classroom whenever students figured-out something that was new to them (p. 22). He also seemed to believe that most discoveries involved recombining or reinterpreting existing facts, ideas, or data. While Bruner (1960) used the term discovery to refer to the product of exploration, he also used the term to refer to the specific process (p. 127). Put simply, students make discoveries by engaging in discovery. Thus, based on Bruner's writing I have synthesized the following definition of discovery learning: Discovery learning is the purposeful activity of the student aimed at uncovering knowledge that they did not possess prior to the learning activity.

Ausubel (1964) argued that scientists' discoveries and those of students in science classes were very different (p. 226). According to Ausubel, if students were given the autonomy of real scientists it would lead to "utter chaos in the classroom" (p. 226). Thus, Ausubel concluded that careful planning was required by the teacher to ensure that students discovered what they were supposed to discover (p. 226). For Ausubel this meant that students engaged in these carefully planned activities were participating in a "contrived" type of discovery (p. 226). Ostensibly, Ausubel's argument is designed to counter the claim that learning by discovery is authentic scientific discovery. However, I think this argument misses the point of what Bruner said about students' discoveries. I do not think that Bruner advocated complete autonomy of the learner while participating in discovery-based learning activities. The discovery-based learning activities he described were carefully planned by the teacher and had specific learning objectives (Bruner, 1968, p. 60), nor, did Bruner claim that student discovery should necessarily mimic the activities of scientists. His argument was that students, through problem-solving and engaging in carefully-planned discovery learning activities could develop skills and knowledge of the discovery processes used by scientists (1961, p. 31).

THE KNOWLEDGE GAINED IN DISCOVERY LEARNING

Bruner (1961) described the characteristics of successful and unsuccessful problem solvers. He described how some children exhibit *episodic empiricism* in solving problems, while others exhibit *cumulative constructionism* (p. 24). Episodic empiricism describes the activities of problem solvers who do not investigate the constraints of a problem or connect new knowledge with old knowledge. They are also unable to effectively reorganize information to facilitate retention (p. 25). Bruner described research that examined the behavior of children as they played a version of the game Twenty Questions (p. 24). Children who exhibited episodic empiricism were not strategic in the questions they asked. Their questions were overly specific and therefore, they did not try to strategically narrow down options. They also seemed to ignore their own question history and therefore did not use old information to inform their current decision-making. Bruner found that these students were more likely to get frustrated because they lacked strategies for coping with large amounts of information.

Bruner suggested that discovery learning promoted the development of a student's problem-solving abilities by "leading him to be a constructionist, to organize what he is encountering in a manner not only designed to discover regularity and relatedness, but also to avoid the kind of information drift that fails to keep account of the uses to which information might have to be put" (p. 26). Therefore, Bruner argued that students' experiences with discovery learning helped them develop problem-solving abilities and skills needed for learning in the future (p. 26). Though he did not use the terms cognitive and metacognitive to describe students' mental operations, I think it is possible to restate Bruner's hypothesis in these terms. It appears that Bruner believed that discovery-learning activities would promote the development of students' cognitive and metacognitive skills and therefore improve their problem-solving ability.

Ausubel (1964) disagreed with Bruner's emphasis on the importance of developing problem-solving ability (p. 233). He argued that Bruner's overemphasis on problem-solving would decrease the amount of time students had to learn the content that is essential to solving problems (p.233). Therefore, Ausubel and Bruner differed in their views of the relationship between problem solving and content knowledge. Ausubel believed that content knowledge laid the foundation for effective problem solving whereas Bruner seemed to believe that by engaging in problem solving students could develop problem-solving skills as well as learn content.

Bruner seems to suggest that problem-solving ability, as well as cognitive and metacognitive skills are spontaneous products of discovery learning. More recent research on problem-solving, cognition, and metacognition suggests that more explicit, focused instruction is required to promote the development of problem-solving ability, as well as cognitive and metacognitive skills (Woods, 1987; Schraw, 1998). Before describing this research I would like to justify my use of research based on problem solving in analyzing discovery learning. I have already stated that inquiry and discovery learning are similar approaches. However, I would also argue that problem solving shares common features with these learning approaches that can make some research on problem-solving relevant to our analysis of discovery learning and inquiry learning. I would argue that discovery learning is similar to problem solving, because in both activities students are presented with a problem or question and then they are expected to engage in self-directed problem-solving activities to arrive at a goal state or solution. I find support for this argument in Klahr's (2000) work where he modeled discovery in science as problem solving that involves search in two spaces, the hypothesis space, and the experiment space (p. 201).

Woods (1987) described several approaches to teaching problem solving. The different approaches he described varied in the amount of explicit instruction dedicated to teaching component skills of problem solving (p. 61-65). The *holistic opportunity* approach that he described gave students many opportunities to solve problems, but did not attempt to help students reflect on their process (p. 61). The *explicit development, embedding, and transfer of components* approach involved practicing individual components skills, embedding these skills in problem solving with domain-specific problems, and then students were given devices that helped them identify when these skills were useful in contexts outside their subject domain (p. 65). Woods' description of effective teaching of problem solving seems to indicate that focused effort is needed to help students develop the cognitive skills they need in problem solving. Whereas Bruner seems to suggest that students are able to develop higher-order cognitive and metacognitive functions spontaneously by engaging in discovery activity, Woods' description of problem solving indicates that the development of these skills is promoted by explicit teacher-led instruction, not student construction. Research on metacognitive skills in educational settings also indicates explicit measures are needed to promote development of these skills (Mayer, 1998; Schraw, 1998). Schraw describes explicit modeling by the teacher, practice and student reflection, as well as the use of student maintained checklists for monitoring their own use of metacognitive strategies. A research study that investigated the effect of *self-monitoring training* on student problem solving performance found that students who received the training were able to solve more challenging problems than those students who did not (Delclos & Harrington as cited in Schraw, 1998). This research leads me to question whether discovery learning on its own, without explicit instruction on metacognitive and cognitive skills, is an effective approach to learning for promoting the development of higher-order thinking skills.

DISCOVERY LEARNING AND MOTIVATION

Bruner (1961) favored White's concept of *competence motivation* over the behaviorist theory of *primary drive reduction* (p. 28). In these models human action is driven by different sources. Behaviorist theories viewed external stimuli as driving the response of the subject. However, competence motivation places the source of stimulus within the individual. The individual is driven to learn and improve his skills because he has an "intrinsic need to deal with the environment" (p. 27). Therefore, Bruner thought that discovery learning provided the necessary environment to induce the shift from extrinsic to intrinsic motivation (p. 28). He suggested that students' learning should not be stimulated by immediate extrinsic rewards; instead, it should be driven by intrinsic rewards that were "long-range and competence-oriented" (p. 28). An autonomous thinker is able to evaluate his own performance (p. 28). He is able to "experience success and failure not as reward and punishment, but as information" (p. 28). Therefore, Bruner seems to suggest that discovery-based learning activities grant students ownership over their learning that allows them to change their perception of their own mistakes (p. 28). The implication is that students in discovery learning activities are motivated, even when confronted with challenges.

It seems to me that in order to benefit from the motivating effects of competence motivation, the student needs to achieve higher-order thinking skills. He needs skills that allow him to "go beyond the information he has been given to generate additional ideas that can either be checked immediately from experience or can, at least, be used as a basis for formulating reasonable hypotheses" (Bruner, 1961, p. 28). Bruner used Vygotsky's theory of mental development to explain how students can develop these high-level thinking skills (p. 28). Vygotsky (1986) theorized that the origin of high-level thought processes could be found in the interaction between the child and his social environment. Therefore, based on this theory Bruner (1961) claimed that students could become autonomous thinkers with the help of the teacher who encourages "the child to participate in 'speaker's decisions'" (p. 28). Therefore, Bruner seems to imply that teacher-student interaction is important in developing the high-level thinking operations necessary for developing intrinsic motivation. It is perhaps true that teacher–student interaction drives the development of the higher mental functions students need to become autonomous thinkers and self-motivated. Furthermore, it might be possible that students learn how to become intrinsically motivated through interaction with others; however, I would argue that other social interactions can also influence student motivation. To be clear, I agree with Bruner that teacher–student interaction and dialogue can positively influence students' intellectual development and the development of positive motivational factors; however, I also find it highly likely that students' social interactions with others at the individual, group, and cultural-levels can influence their motivation, both positively and negatively. In addition, I believe students arrive at school with dispositions that have been shaped by their social milieu.

Ausubel's (1964) primary argument against the professed motivating force of discovery learning is that some students will fail to meet the learning objective of the learning activity (p. 233). He concedes that there is great potential for discovery learning approaches to excite students and motivate them to solve problems (p. 233); however, he suggests that not all students will succeed in making discoveries, and therefore their self-confidence and motivation could be damaged.

What does research say about the motivating effects of discovery learning? Bruner described two factors that would allow students to become motivated when they are engaged in discovery learning: intellectual ability and control over their own learning. Students needed to be given some level of autonomy over their learning, but Bruner also seemed to recognize that they needed to have the intellectual ability to benefit from this autonomy; however, I would argue that his hypothesis ignores several factors related to motivation that are important to consider. Individual differences in students may contribute to differences in motivation during discovery learning activities. Put simply, some students will be highly motivated by certain discovery learning activities while others will not (Brown as cited in Snow, 1987, p. 281). Also prior knowledge and experience will affect how students respond to discovery learning activities. It is difficult to imagine giving an entire class of students a problem that they will all find to be equally difficult. Ausubel (1964) focused on the students that may fail during discovery learning and how this would impact their motivation negatively (p. 233), however, we might also consider the student for whom solving the problem is trivial. This student may not be motivated to solve the problem if he does not perceive the problem to be sufficiently challenging.

Research suggests that self-efficacy is related to students' motivation. Students identify cues from the environment that contribute to their feelings of self-efficacy (Mayer, 1998, p. 59). Students have multiple sources of self-efficacy: Self-assessment based on performance relative to the task and relative to others, assessment of their performance made by others, and their "physiological state" (p. 58). Bruner's hypothesis described students' self-assessment as being a source of intrinsic motivation; however, recent research suggests that students' evaluation of their own performance is shaped by multiple factors. The classroom is an environment where students' are involved in self-reflection but they are also interacting with other students and the teacher. It seems reasonable to assume that all of these interactions affect students' evaluation of their own performance. Furthermore, it is highly likely that these interactions affect different students differently. Common sense and experience in the classroom tells us that different students respond differently to the same teacher feedback. Similarly, students respond differently to feedback from their peers. Therefore, while discovery learning might be an approach that positively influences student motivation, current research indicates that it is likely one factor among many that we should consider when we evaluate educational interventions that claim to promote student motivation.

LEARNING HOW TO DISCOVER

Bruner (1961) wanted to promote students' abilities to successfully engage in inquiry. He indicated that scientists possessed certain attitudes and knowledge of specific activities that allowed them to carry out their research (p. 30). In addition to specific attitudes and knowledge, Bruner also identified that the "intuitive familiarity" of scientists was important in making discoveries (p. 30). He hypothesized that if one engaged in inquiry he would be able to generalize his knowledge and transfer it to "almost any kind of task" (p. 31). Thus, he expressed a belief that students could become better problem-solvers through practice and by being given the opportunity to discover knowledge. Furthermore, he expressed a belief that students' skills and knowledge related to discovery were transferrable.

As mentioned previously in this essay, Ausubel disagreed with Bruner's belief that students could be expected to engage in authentic scientific discovery. Ausubel (1964) expressed skepticism about the creative and intuitive abilities of students (p. 231). He argued that the nature of intuitive thinking of students is wholly different than that of scientists (p. 232). I find Ausubel's argument compelling. I think that scientists' intuitive thinking is based on tacit knowledge that consists of *scientific concepts* (Vygotsky, 1986, p. 146), however, I believe that students' intuition is likely to be based on a tenuous grasp of conceptual knowledge and relies heavily on their *spontaneous concepts*. I find support for this where Ausubel (1964) writes "children are notoriously subjective in their evaluation of external events, and tend to jump to conclusions, to generalize on the basis of limited experience, and to consider only one aspect of a problem at a time" (p. 231). Furthermore, Ausubel argued that scientists have an understanding that their intuitive guesses are fragile and tenuous and only provide temporary scaffolding for more rigorous investigation (p. 232). Many students do not possess this *metaknowledge* of the discovery process and therefore use their intuitions to form, what they consider to be, viable explanations of phenomena. Ausubel captures the essence of this argument by stating that a student demonstrates intuitive thinking "not because he is creative, but because this is the best he can do at his particular stage of intellectual development" (p. 232).

Ausubel (1964) also disagreed with Bruner's claim that students' knowledge of the discovery process could be generalized or transferred to other subject domains (p. 231). He did not believe that learning how to discover in one subject domain transferred to other subject domains (p. 231). Nor, did he believe one could learn a general set of heuristics for discovery that would be useful in making discoveries in specific domains.

Klahr and Nigam (2004) performed research aimed at assessing the relative effectiveness of discovery learning and direct instruction in promoting transfer of learning. Their study included 112 third and fourth graders (p. 1). One group of students learned about experimental design via direct instruction, the other group learned through self-directed experimentation with no teacher feedback or explanation (p. 4). In both cases students set-up an experimental apparatus to observe the effects of different variables on the outcome; however, students in the direct instruction group received additional explanation from the teacher where the teacher demonstrated effective experimental designs as well as ineffective ones (p. 4). The transfer test was administered one week later and required students to assess the experimental design represented by science fair posters. The researchers found that some students in both treatment groups mastered the principles of effective experimental design (p. 7). They were surprised to find that performance on the transfer test appeared to be independent of the type of instruction students received (p. 7). While these findings do not show that discovery learning was more effective than direct instruction, they do seem to support Bruner's (1961) hypothesis that knowledge gained in discovery learning can be transferred to other problems (p. 31). Students in this study demonstrated that they learned about the discovery process by engaging in discovery. Specifically, they learned about the role of controlled variables in experiments. What remains unclear is whether student knowledge of discovery processes can be transferred to other subject domains. This study examined transfer of only one aspect of the discovery process, the control of variables. Therefore, it is also interesting to consider whether all conceptual and procedural knowledge related to the discovery process can be learned through discovery and transferred.

DISCOVERY LEARNING IMPROVES RETENTION

Bruner (1961) suggests that teaching should help the student store and recall information more efficiently. He argued that helping students understand fundamental principles and concepts allowed them to efficiently store information (Bruner, 1977, p. 24). He described how scientists' ability to store mathematical formulas in long term memory allowed them to "regenerate the details on which the more easily remembered formulas is based" (p. 24). He also hypothesized that "figuring out or discovering things for oneself also seems to have the effect of making materials more readily accessible in memory" (p. 32). He cited research from the field of psychology that demonstrated that people who were instructed to use memory strategies were better able to recall word pairs (p. 32).

Alfieri and Tenenbaum (2011) pointed out that much of the psychological research that is used to support the positive outcomes of discovery learning, such as high retention, are based on simple tasks (p. 3). It seems reasonable to question whether psychological research based on retention of word pairs is an appropriate comparison for how students store and recall more complicated procedural and conceptual knowledge. Kittel (as cited in Mayer, 2004) studied the immediate and delayed retention of students who received different types of instruction. He found that guided discovery groups retained information the best and the pure discovery groups retained information the worst (p. 15). Tuovinen and Sweller (1999) found that for students with little or no prior knowledge exploratory learning was ineffective. On the basis of such poor performance in this group they concluded that it would be highly unlikely that this group of students would demonstrate high-retention of knowledge (p. 340). Kersh (1962) studied the ability of high school math students to learn and remember unfamiliar rules of addition. He concluded that "lecture-drill techniques" in some cases were more effective than teaching methods that attempted to "develop understanding" (p. 69). Wittrock (1963) determined that varying amounts of guidance in learning contributed to differences in retention and transfer. He concluded that an "intermediate amount of direction produced the greatest retention and transfer, but a 'maximum' amount of direction produced the greatest initial learning" (p. 183). He found that the "minimum direction group" performed the worst on retention tests (p. 183). Worthen (1968) pointed-out that research in the 1950s and 1960s found both expository and discovery methods superior in promoting retention (p. 1). This conclusion is reiterated by Prince and Felder (2006, p. 133). Therefore, it is difficult to draw conclusions from the extant research on the effect of discovery learning on retention, given that the various studies investigate acquisition of different types of concepts and use different types of instructional methods; however, what does seem clear is that no teacher guidance, or what is called pure discovery learning, seems not to be an effective method for promoting retention.

CONCLUSION

Current science curriculum reforms are recommending inquiry-based learning approaches. In an attempt to evaluate the validity of these learning approaches I revisited Bruner's writing about discovery learning and highlighted the benefits of discovery learning that he proposed. I described Ausubel's arguments to help evaluate the logic and assumptions of Bruner's ideas about discovery learning. Furthermore, I described some of the empirical research related to some of the benefits of discovery learning to evaluate Bruner's hypotheses. Finding empirical research that is relevant to this task is challenging since there is little agreement on terminology. Based on the criticism provided by Ausubel (1964) as well as empirical research I am led to conclude that inquiry-based learning approaches could be an effective way to learn science; however, I think that research from the past fifty years provides us with additional insight in to the nature of problem solving, motivation, and cognition that may help us develop inquiry-based learning activities that are more likely to be effective. I assert that new formulations of inquiry learning approaches need to recognize that the acquisition of higher-order cognitive and metacognitive functions does not spontaneously develop as a result of student-centered, problem-based learning activity. Explicit instruction may be necessary to teach the component skills for effective self-directed problem solving. These component skills consist of cognitive, metacognitive, and affective skills. For inquiry learning activities to be effective for all students teachers need to take in to account the individual differences of students. Student differences in prior knowledge, motivational levels, interests, and self-efficacy need to be considered in the design of inquiry learning activities if they are to be effective. If the goal of inquiry learning approaches is to promote transfer then I believe more explicit instruction is needed to help students see how their specific subject-domain skills and knowledge could be used in new situations.

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Bruner and Ausubel: What do we learn from their theories?

Patrick Morasse
University of Massachusetts, Lowell

ABSTRACT

This paper is a summary of my understanding of the learning theories of Bruner and Ausubel. Recently, I have been studying a number of learning theories including those proposed by Bruner, Gagne, Davis, Hendrix, Adler, and Ausubel. I chose to reflect on the theories of Bruner and Ausubel, because they are somewhat in opposition to each other and although more than forty years have passed since their debate began, it continues to be relevant today. Bruner proposed a form of discovery learning, while Ausubel suggested a form of reception learning. Interestingly, if someone were currently asked why discovery learning is sometimes preferred, his or her response might be aligned with Ausubel's idea of meaningful reception learning. As Marzano (2011) suggests, many people believe discovery learning is superior because "constructing one's own meaning must be more effective" (p.86). However, according to Ausubel (1973a), meaningful reception learning also requires that students create meaning for themselves, rather than rote memorization. Perhaps that indicates both Bruner and Ausubel were describing what presently would be considered forms of discovery learning.

In many cases, learning theorists use the ideas of psychologists such as Piaget and Vygotsky as foundations for their learning theories. However, learning theories are specifically designed to enhance the education of students in schools or other structured learning environments. In other words, learning theories do not describe the psychological development of children, but rather, they suggest what is valuable for students to learn and how conditions should be arranged to ensure students have the best opportunity to learn. In order to better understand and communicate my ideas concerning learning theories, I have chosen to compare Bruner's theory of education to Ausubel's theory of reception learning.

Ausubel (1973a) distinguishes between discovery learning and reception learning (p.149). He emphasizes that students must discover a concept for themselves in discovery learning, while concepts are presented to students in reception learning. Ausubel (1973a) suggests that in both cases students "internalize the material or incorporate it into their cognitive structure so that it is available for reproduction or other use at some future date" (p.149). Later in this paper, I will describe more specific characteristics of Bruner's discovery learning and Ausubel's reception learning. First, I summarize what I consider important factors behind both theorists' recommendations. In particular, it appears the methods of learning recommended by Bruner and Ausubel are directly related to their perspectives regarding what students should learn, what students are ready to learn, and how students can best transfer what they learn.

GUIDING PRINCIPLES

Goals of Learning

Some of Bruner's (1973) goals of education are for learning to provide "a sense of delight", "bestow the gift of intellectual travel beyond what is given", and be "useful" (p.133). Bruner proposes the greatest intellectual enjoyment comes from being able to understand complex ideas in their simplest terms. He also suggests that generalizing improves the ability of students to apply knowledge beyond its original setting. In regard to usefulness, Bruner explains that directly applicable knowledge is worth learning. Perhaps most critical is Bruner's suggestion that students can achieve all of the goals above by discovering the fundamental ideas of a discipline. In Shulman's (1973) view, Bruner emphasizes the importance of not only the knowledge gained by students, but also the process of gaining that knowledge (p.8).

Meanwhile, Ausubel (1973b) suggests schools should focus on teaching "both what is important to cultural survival and cultural progress, as well as what is most teachable to the majority of its clientele" (p.236). According to Ausubel (1973a), most students will never become great problem-solvers, critical thinkers, or creative thinkers (p.151). Therefore, it is more valuable to teach content rather than thinking skills, which are unlikely to become well developed in the majority of students. However, Ausubel (1973b) later clarifies this point, suggesting there is a place for problem solving in education, but it is not the main purpose of education (p.233). In my view, Ausubel's interest in maximizing the amount of content students learn, separates him from Bruner, who appears more interested in students learning how to gain knowledge.

Readiness

Bruner has a unique position on readiness. He suggests any material can be aligned with any student's level of cognitive development or ability to think abstractly. According to Shulman (1973), Bruner proposes that all material can be represented at the enactive level, iconic level, and symbolic level (p.6). The simplest level of representation or enactive level, involves students manipulating physical objects in order to gain an intuitive understanding of basic principles. As they become older, students develop the ability to manipulate mental images, no longer requiring physical objects. Mental images are a form of representation at the iconic level and students can work with them once they are capable of thinking somewhat abstractly. In the symbolic level, which is the most abstract level of representation, students are able to work strictly with symbols, no longer relying on physical objects or mental images. As a result of his belief in these levels of representation, Bruner (1973) suggests "any subject can be taught to anybody at any age in some form that is honest" (p.133). Since mathematical language is symbolic, Bruner warns against using it too early.

Like Bruner, Ausubel also believes in stages of cognitive development, but his ideas of readiness are quite different. According to Ausubel (2002), readiness is a combination of "genic effects", cognitive growth, and cognitive experiences (pp.293-294). By genic effects, I believe Ausubel is referring to the inherent traits of a person, which are a product of their genetic code. Ausubel (1973b) also suggests the cognitive development or general readiness of children impacts what they can learn and how they should learn (p.225). For example, students operating in the concrete stage of development must have physical objects present when they are learning (p.225). Meanwhile, children in the abstract stage of cognitive development can learn more efficiently without physical objects. Ausubel also describes the concept of specific readiness, which is a measure of students' ability based on their experiences in specific disciplines. Specific readiness impacts students' ability to learn new concepts in those disciplines. For example, students generally operating in the abstract level may temporarily operate in the concrete level when beginning to learn a completely new discipline. On the other hand, students with a strong foundation in a certain discipline are more likely to easily learn new concepts in that discipline. I believe the major difference between Ausubel's view of readiness and Bruner's view is that for Ausubel readiness determines when to learn something and for Bruner readiness determines how to learn something.

TRANSFER

In addition to readiness, Bruner and Ausubel propose very different ideas regarding transfer of knowledge. According to Shulman (1973), Bruner believes a great deal of transfer can occur from one learning experience to another, even across disciplines (p.13). This can happen either when students learn the fundamental aspects of a subject or when they learn strategies for getting knowledge. Bruner (1977) suggests understanding fundamental ideas helps students gain a deep understanding of the most basic principles of a subject and therefore, lead to the greatest number of applications of that knowledge (p.18). Shulman (1973) provides an example of Bruner's idea of transfer between disciplines by suggesting the fundamental idea of "balance" can be related to balance in equations, ecology, politics, or economics (p.13). By grasping the fundamental idea of balance, students are better prepared to build knowledge not only in a specific discipline but in various areas. In regard to the transfer of knowledge-getting processes, Bruner (1977) believes students who learn to solve problems and make discoveries on their own, are more likely to be successful afterwards (p.27). As a result, he encourages learning opportunities focused on heuristics and problem-solving strategies, as well as allowing students to learn as scientists do.

In Ausubel's (1973a) theory, knowledge is transferred when newly presented ideas are closely related to students' prior knowledge (p.154). In order to maximize transfer power, students should categorize, distinguish between, and generalize from material they are learning. Additionally, Ausubel (1973b) suggests students should verbalize their thoughts, which will not only display their understanding, but also increase their understanding and ability to transfer knowledge (p.227). According to Ausubel, the process of connecting, categorizing, distinguishing between, and verbalizing ideas is what increases retention. Unlike Bruner, Ausubel does not express the belief that knowledge is easily transferable from one discipline to another. Instead, he focuses on the importance of making connections within a discipline to help increase understanding and retention.

SUGGESTED METHODS OF LEARNING

BRUNER'S DISCOVERY LEARNING

Rothstein (1990) defines discovery learning as "an approach to learning developed by Jerome Bruner in which students learn by doing and discover general principles from specific examples and details" (p.363). In my view, Rothstein is indicating that during discovery learning activities, emphasis is placed on students determining generalities from patterns they recognize. It seems important that principles are not presented to students in a formal manner. Instead, students must discover those principles for themselves. Therefore, discovery learning is a process of inductive reasoning.

There are various forms of discovery learning, depending on expectations for student learning and the role of teachers. Shulman (1973) compares Bruner to Gagne in order to distinguish between their two concepts of discovery learning. Shulman (1973) explains that Gagne's proposed form of discovery learning involves students being guided substantially by the teacher in order to systematically learn specific objectives that build on each other (p.10). In comparison, Shulman says Bruner's idea of discovery learning is far less direct. In other words, Bruner believes students should be allowed to struggle more as they make discoveries. Unlike Shulman, Rothstein (1990) describes Bruner's discovery learning as guided discovery, because Bruner believes teachers should provide some guidance to students.

Bruner (1973) expects students to begin learning by developing an intuitive understanding of general principles. According to Beberman (in Bruner, 1973), "somewhat related to the notion of discovery in teaching is our insistence that the student become aware of a concept before a name has been assigned to the concept" (p.128). Students may begin developing an intuitive understanding of concepts by manipulating concrete materials, which are in the enactive level of representation. Eventually, when students are ready, they may advance to working with representations at the iconic level and symbolic level. This is related to Bruner's (1973) "spiral curriculum", in which students return to the same ideas at various times in their learning, building a deeper understanding of the material (p.132). By engaging with the same material, but in different manners and at the appropriate times, students become masters of that material. As a result, students increase their ability to transfer knowledge.

To this point, discovery has been described as a means of learning content. However, Bruner is not only interested in the products of learning. According to Bruner (1973):

> Discovery is better defined not as a product discovered but as a process of working, and the so-called method of discovery has as its principal virtue the encouragement of such a process of working or, if I may use the term, such an attitude. (p.127)

Bruner (1973) suggests students should experience discoveries for themselves, as the reward of discovery is superior to extrinsic rewards such as "competition" and "gold stars" (p.128). According to Bruner (1973), "discovery, with the understanding and mastery it implies, becomes its own reward that is intrinsic to the activity of working" (p.128). Here, I believe Bruner is implying that students perceive themselves as more successful in discovery learning than in other methods of learning and, as a result, are more motivated to work diligently using this method.

CRITICISM OF DISCOVERY LEARNING

I find that discovery learning is most often criticized for being a time consuming process. For example, Rothstein (1990) suggests both teacher preparation and student learning can be time consuming in discovery learning (p.163). Ausubel (1973b) seems to agree, proposing that discovery learning is "inordinately time-consuming, wasteful, and rarely warranted" for secondary school and college students (p.229). Even Bruner (1973) agrees that students "cannot wait forever for discovery" (p.128). However, according to Cronback (1973) some research indicates discovery learning can be a more time efficient method of learning than reception learning. Also, some proponents of discovery learning, such as Dean and Kuhn (2007) argue that even if discovery learning is more time consuming to begin, students eventually retain more.

Another criticism of discovery is that it may only be valuable to students of a certain age group. Ausubel (1973b) admits discovery learning may be somewhat useful for students in the concrete stage of development, but not for students in the abstract stage of development (p.225). He explains that students in the abstract stage of development learn best by connecting abstract ideas. However, he does agree that students who are completely unfamiliar with a discipline may briefly benefit from concrete experience, even if they are in the abstract stage of development. Ironically, Rothstein (1990) suggests that discovery may be too difficult for students who are not cognitively developed enough (p.163).

One of Cronback's (1973) concerns regarding discovery learning is that a discovery is "at best meaningful only to the student who discovers it, not to the many who fail to make the discovery" (p.45). Ausubel (1973b) agrees, suggesting that discovery learning activities must be organized so that all students will make the discovery (p.226). Bruner (1973) is prepared to respond to this criticism, because he recommends increasing students odds of discovery when he states that "teachers should find what ideas have been presented earlier and deliberately use them as much as possible for teaching new ideas" (p.132). It appears most criticisms of discovery leaning have been responded to with logical or evidence based explanations.

AUSUBEL'S RECEPTION LEARNING

Rothstein (1990) defines expository teaching as "a method of learning developed by David Ausubel involving deductive reasoning and receptive learning" (p.364). Ausubel (1973a) indicates reception learning is a method in which students obtain content knowledge through communication (p.149). A major difference between discovery learning and reception learning is that discovery learning involves inductive reasoning, while reception learning involves deductive reasoning.

Despite his arguments for reception learning, Ausubel (1973a) suggests the most important issue is not whether one chooses a particular method of instruction, but that learning is meaningful (p.150). In order for learning to be meaningful, students must be able to connect new content to prior knowledge, making it nonarbitrary. When content is nonarbitrary to students, it is not only more meaningful, but also better retained. This indicates to me that reception learning is only sufficient if students have the prior knowledge to form understanding of the material being presented.

One way Ausubel (1973a) recognizes meaningful learning is if students can describe their knowledge in a nonverbatim way (p.150). In other words, students should be able to explain concepts in their own words if they have achieved meaningful learning. Ausubel (1973b) suggests the process of verbalizing understanding in nonverbatim terms not only demonstrates, but also increases understanding (p.227). According to Ausubel (1973a), it is also important for students to understand content in nonverbatim terms, because it is easier to remember only a concept, rather than a concept and a verbatim definition associated with it (p.150).

Another important aspect of reception learning is the idea of discriminability. Ausubel (1973a) indicates that students must be able to distinguish between ideas, or new ideas will not be remembered (p.156). Prior to student learning, he suggests teachers should introduce advance organizers. Advance organizers are designed to help students effectively build their knowledge by presenting connections and distinguishing between new and prior knowledge. Ausubel (1973b) suggests students cannot be responsible for comparing all ideas on their own. Instead, teachers should make similarities and differences clear to students (p.156). I believe this is much easier to apply during reception learning, rather than discovery learning, because the teacher is expected to present ideas to students during reception learning. During discovery learning, the teacher may ask students how certain ideas are similar or different, but probably would not supply such information to students directly.

CRITICISM OF RECEPTION LEARNING

One argument against reception learning is that students may not be able to comprehend the material being presented to them. Bruner (1973) suggests students and teachers may not share the same language, so students as listeners in reception learning, may not grasp the concept being taught (p.131). He continues, by adding that in discovery learning students play the role of both speaker and listener. However, I do not believe this argument qualifies as a criticism of Ausubel's meaningful reception learning, because Rothstein (1990) describes Ausubel's idea of reception learning as including “considerable interaction between the students and the teacher” (p.164). Therefore, the student is not only a listener, but also a speaker in meaningful reception learning.

A second criticism of reception learning is that it may not be the most motivating method of learning for students. Ausubel (1973a) demonstrates concern that reception learning is not meaningful unless students are motivated to make meaning according to their own knowledge base (p.153). Otherwise, learning becomes rote memorization, which is less likely to be retained or transferred. According to Bruner (1977), students who learn by discovery will have an improved attitude toward learning, because of the excitement produced both during and after making discoveries (p.22). However, Ausubel (1973b) does not necessarily agree, suggesting there is a difference between the excitement of students making discoveries for themselves and scientists making original discoveries (p.233). Additionally, Ausubel (1973b) suggests excitement is not always a product of the learning method, because students can be excited about learning as a result of “exposure to competent teaching” (p.233). I do not believe the general criticisms of reception learning are applicable to Ausubel's suggested form of reception learning, because he is focused on students as individuals, which removes most of the stigmas associated with reception learning.

CONCLUSION

In my view, Bruner and Ausubel display some beliefs that are closely related and others that are extremely different. Similarities include their ideas about the importance of prior knowledge, general concepts, and the role of teachers as facilitators to student learning. Both Bruner (1977) and Ausubel (1973a) suggest students must form their own understanding of concepts. At the same time, they have contrasting ideas about readiness, transfer, and the overall goals of education. I believe those views lead them to support or criticize certain methods of learning. After analyzing both sides, I agree with Cronback (1973) that a combination of discovery learning and reception learning may be best (p.47). After all, Ausubel (1973b) suggests that discovery may be best under certain circumstances and Bruner (1977) admits that discovery learning is too time-consuming for all of the material students should learn.

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Optimizing Learning Kinematics Concepts When the Graph Is Delayed

Edward P. Tonelli
University of Massachusetts Lowell

ABSTRACT

Kinematics concepts are fundamental to learning Newtonian physics. Most high school and college students fail to understand even the most basic of these concepts; their thinking is dominated by misconceptions. Predicting, testing, and evaluating predictions about various aspects of motion are all crucial to helping students to 'un-learn,' (that is, change) their misconceptions and to learn correct concepts. Creating and interpreting graphs is crucial to the process of testing and evaluating predictions, because graphs make abstract concepts and relationships visible to the student. Real-time graphing programs (RTGs) can play a vital role in the graph creation and interpretation process. Changing concepts may work best when students practice a scientific methodology. RTGs have been shown to help students to practice many important aspects of scientific methodology. However, research has indicated that when a delay of as little as 20 seconds occurs between the observed event and the resulting graph, the learning effect of using the RTG may be lost. When a 20-second delay occurs during an inquiry-based lab, where the students ask their own questions, predict results, collaborate, reflect, and evaluate data, that delay may not have as critical an effect on student learning as such a 20-second delay might have during a cookbook-style lab where students are hardly thinking at all. However, the effect of such a delay must be further examined to ascertain the degree of the effect it may have on students in the scientifically based process of concept change.

The following joke, from 1980 or so, very well illustrates this statement (that it's not very easy to find good uses for computers in math teaching):"How do you teach mathematics using calculators? 'Two calculators plus three calculators are five calculators.'" Szendrei (1996), p. 432

The First Problem: School Lab Delays May Impede Student Learning Many educators have stated that educational laboratory probes, sensors, and software that graphs the data at the same time that the data is collected, (hereinafter, real-time graphing programs, or RTGs) are tools which may be essential for helping high school students to learn kinematics concepts. Halliday, Resnick, and Walker (1997) define kinematics as "the classification and comparison of motions" (p. 12). If one compares pre-treatment test scores with post-treatment test scores in many studies where RTGs were part of the treatment, kinematics RTGs appear, at first blush, to offer great hope to physics students. For instance, Bayraktar's (2001) meta-analysis shows that generally, when electronic sensors combined with graphing software (hereinafter, 'probeware') and RTGs have been used as tools in traditional physics and chemistry courses, students have performed markedly better on post-tests than students who studied without the electronics. Other examples demonstrating correlations between RTG use and higher post-test scores in kinematics are plentiful.[1]

Other studies and meta-analyses have challenged the positive correlations between RTG usage and higher achievement on post-tests. For example, Lindwall and Iversson (2004) state that over 20 years of research into science lab treatments using probeware and other technologies had indicated no large trends of learning gains. For the sake of argument, this paper accepts that using RTGs *can* be effective at helping students to learn kinematics concepts.

The problem, a significant one, is as follows: Even if using RTGs can help students to learn kinematics concepts, Brassell (1987) found that when using RTGs, if a delay of as little as 20 seconds occurred between the observed motion and resulting graph, then the tool's effect on the students' learning was almost totally nullified (pp. 393-394). Results of post-tests showed that students who experienced short delays performed no better on the post-test than students who had not used the RTG at all (pp. 391-392). This finding (hereinafter referred to as 'Brassell's assertion') has been cited in scores of subsequent studies, but has not been fully examined. Because the students in Brassell's (1987) study were examining graphs of speed versus time and distance versus time, fundamentals of learning mechanics in Physics, the finding is quite troubling. Even when many kinds of computer software are user-friendly, teachers and students make mistakes, and delays occur. This is also true

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[1] Brassell (1987) is but one researcher who has found higher kinematics post-test scores for high school kinematics RTG users than for RTG non-users. Kozhevnikov and Thornton's (2006) one-semester study of college introductory kinematics students shows that after using RTGs, students initially assessed as strong at visual and spatial ability were observed to lose their initial advantage to students who had been assessed as weak in those same abilities. Pre- and post-testing revealed that RTG users weak at visual and spatial abilities improved more than those who did not use the RTGs. Thornton and Sokoloff (1990) and Sokoloff, Laws, and Thornton (2007) each have found that students using RTGs instead of going to lectures made far fewer errors on post-test kinematics questions than students who had gone to lectures instead of using RTGs.

of RTGs. Drayton, Flak, Hammerman, Hobbs, and Stroud (2010) report that sensors and real-time graphing programs helped students when they worked, but such programs did not work all the time. Dunleavy, Dede, and Mitchell (2009) found that even when technicians from MIT were helping with high school MBL technologies, breakdowns disrupted and slowed student lab exercises. Machines not fully under the control of MIT technicians can certainly fail when in the hands of people less technologically capable. If Brassell's (1987) assertion is absolutely true, then students encountering delays in even the best-taught classes may not be learning kinematics concepts.

The Second Problem: American University Students Do Not Know Kinematics Concepts When Hestenes, Wells, and Swackhamer (1992) introduced their Force Concept Inventory to college physics professors, most of the professors thought the questions were too basic for university students. Many of these same professors were reportedly shocked by the poor performances by many of their students (p. 142). Thornton and Sokoloff (1998) reported a similar initial professorial distain for the simplicity of their Force Motion Conceptual Evaluation, followed by the shock of learning that most of the distance and speed questions were answered correctly by fewer than 20% of the students in a high-level, calculus-based course (p. 338). Rosenquist and McDermott (1987) found that most university students could not correctly answer kinematics questions, nor accurately interpret kinematics graphs (p. 407). Halloun and Hestenes (1985b) found that even after taking a full semester of calculus-based physics, most students could correctly answer only two-thirds of the questions about the most fundamental principles of kinematics (p. 1048). McCloskey (1983) found that students in introductory-level university physics courses indicated through their answers on qualitative post-test questions that falling bodies fall at a steady rate from the time they are dropped (p. 319). There are a host of other studies that show that American adults, including those who *should* know kinematics principles the best (Clement (1982) found that even engineering students mistook inertia for force on motion graphs (pp. 68-69)), do not understand[2] even the most basic concepts. In an economy that demands more and more workers with technical expertise, having few university students who are proficient at physics is not a promising development. The prevalence of this problem is common knowledge to the American public. The problem of American ignorance of kinematics concepts is not restricted to the universities—it is also a problem among the high school students who eventually populate the university classrooms. This literature review focuses on learning among high school students, but draws information from studies of middle school and university physics students as well.

Possible Solution: Concept Change Through Student Prediction, Testing, and Evaluation of Predictions, Using RTGs and Graphs As Testing and Evaluation Tools. According to Strike and Posner (1992), "novice learners do not approach learning with blank slates. They approach new ideas with prior conceptions that govern their interactions with them" (p. 152). If students base their knowledge of kinematics on their observations of everyday life, then they will have little chance of understanding Newtonian physics, which is based on an ideal, rather than a readily-observable situation. There is little, if anything, in observable, terrestrial nature that moves in un-accelerated motion. To learn kinematics requires students to set aside their experiences in favor of ideal definitions. Many scholars recognize the extreme difficulty of setting old conceptions aside, or considering new information, sufficient to inspire a re-conception of ideas. (Newton's ability to do both of these set him aside as a genius). Strand One of this literature review discusses the fundamental nature of kinematics concepts, as well as some of students' more common misconceptions about it. Strand One next considers the role of prediction in helping students to test and evaluate their own ideas about kinematics. It looks next at the crucial role that graphing and graph interpretation plays in the prediction, testing, and evaluation process. Strand One then considers the possibility that through using a scientific approach to learning, students may be able to 'un-learn' their kinematics misconceptions sufficiently to learn how kinematics principles actually work. RTGs can play a vital role in the graph creation and interpretation process, so their role is also considered. If a concept change approach (discussed below), based in the practice of a scientific methodology is crucial for students to 'un-learn' misconceptions and to learn correct kinematics concepts, then their practice of scientific methodology must be reviewed. Therefore, Strand Two considers whether RTGs have been effective not only at helping students to learn kinematics principles, but also at helping them to practice scientific methodology. When placed in the context of scientific methodology in the classroom, Brassell's assertion is challenged. A 20-second delay that occurs in an inquiry-based lab where the students are asking their own questions, predicting results, collaborating, reflecting, and

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[2] There is some debate over the meaning of the word 'understand.' To Thornton and Sokoloff (1998), 'understand' means to answer correctly on post-test questions (pp. 340-341), while to Trowbridge and McDermott (1981) 'understand' means to be able to demonstrate the concept on a post-treatment interview (p. 242). The distinction between these two understandings of 'understand' loses its importance when one considers that no matter whose conception one adopts, students fail to understand kinematics principles.

evaluating data *may not have* as critical an effect on student learning as such a 20-second delay might have during a cookbook-style lab where students are hardly thinking at all. However, the effect of such a delay must be further tested to ascertain the degree of the effect it may have on student learning in several contexts.

STRAND I

MOTION AND MOTION GRAPHS

Every body continues in its state of rest, or of uniform motion in a right line, unless it is compelled to change that state by forces impressed thereon.… The alteration of motion is ever proportional to the motive force impressed; and is made in the direction of the right line in which the force is impressed. Newton (1848) p. 83.

The Study of Kinematics Concepts Is Fundamental To Learning Physics Some exposure to Newton's first and second laws is required in virtually every middle and high school physics curriculum. These two laws involve force, a concept which high school and college students in math-based courses normally investigate after examining kinematics. Implied in the two laws is that a change of speed or direction of movement *is the evidence* of the application of a force on an object. To quantitatively determine changes in speed and direction requires the student to be fluent in the study of kinematics. According to Halliday, et al. (1997), a displacement or distance is "a change from one position, x_1, to another position, x_2, in a straight line" (p. 12). Average velocity is "the ratio of the displacement…that occurs during a particular time interval"…(p. 13). Additionally, "the slope of the straight line that connects two particular points on the $x(t)$ curve" is the average velocity of the object (p. 13). "How fast a particle is moving at a given instant…is its instantaneous velocity (or simply velocity) v (p. 15). Halliday, et al. (1997) then provide several formulae that express instantaneous velocity as a limit. "Speed is the magnitude of velocity," velocity with no indication of direction (p. 15). "When a particle's velocity changes, the particle is said to undergo acceleration (or to accelerate)" (p. 17). Halliday, et al. (1997) then explain that acceleration is the derivative of velocity. "An interaction that causes an acceleration of a body is called a force, which is, loosely speaking, a push or a pull" (p. 82).[3]

The recommendations of several national science education research bodies loosely reflect the hierarchy of concepts which places displacement first, speed second, and acceleration third in the learning order. According to the National Research Council (NRC) (1996 and 2011), and the American Association for the Advancement of Science (AAAS) (2009), middle school students should attain an informal or qualitative conceptual understanding of kinematics concepts, while for high school students, the goal is a more formal, quantitative understanding.[4]

Furthermore, many of the NRC's (2011) recommendations reflect the findings of the extensive body of educational research into child development and appropriateness of studies for students of various ages. Such studies include the extensive work of Piaget (1946) and the more recent work of Dykstra and Sweet (2009). A full review of these findings is outside the scope of this review of literature.[5] Individual researchers are also in agreement with the ordering of the concepts as stated in Halliday et al. (1997). For example, Halloun and Hestenes (1985b) stated generally that when studying physics, the study of kinematics comes first (p. 1043). According to Trowbridge and McDermott (1980), students need work with displacement and velocity first because the rest of mechanics is built on those two concepts (p. 1020). Similarly, according to Beichner (1994), to

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[3] Although these formal (math-based) definitions are well-known to science educators, they illustrate the point that if the student in a math-based physics course does not comprehend the formal concept of displacement, the student cannot comprehend the formal concept of velocity. Similarly, if the student fails at understanding the concept of velocity, the student will fail to grasp the formal meaning of acceleration. Finally, if the student does not know the formal meaning of acceleration, then the formal concept of force will be a vagary, as the evidence of the existence of any force is the acceleration of the body being pushed or pulled. Halliday, et al. (1997) implies a hierarchy of concepts by presenting formal definitions (displacement, followed by velocity, followed by acceleration, followed by force) in a specific order. Myriad other physics textbook and curriculum developers present either identical or closely similar hierarchies. A firm grasp of kinematics, then, is required to study of Newtonian physics.

[4] For example, the AAAS (2009) expects fifth graders to know that forces cause changes in speed, and that the bigger the force, the bigger the change in speed (Motion). By the end of 8th grade, students are expected to know that unbalanced forces result in changes in speed, and by the end of the 12th grade, students are expected to be able to make quantitative predictions of motions with Newton's Second Law (Motion). Similarly, the NRC (2010 Science) states that by the 8th grade students should know that unbalanced net forces result in speed changes, and by 12th grade, students should be able to quantify macroscopic changes in speed and make quantitative predictions of motion after application of forces (Physical Science—Motion and Forces). The NRC (1996) states that by the 8th grade, students should be able to describe motion, position, direction, and speed qualitatively (p. 154), while by the 12th grade, they should be able to use mathematics to analyze positions and speeds, as well as to use technology to test and revise predictions (p. 175).

[5] See footnote next page

study physics, kinematics is a 'building block' (p. 750) upon which rests the rest of the study of physics.

Indeed, the order in which the NRC (2011) sets out the sciences suggests that kinematics principles are fundamental to the other elements of physics, and even the other sciences. NRC (2011), presents the topics from 'Types of (physical) Interactions' to 'Stability of Physical Systems' to 'Conservation of Energy' to 'Energy in Chemical Reactions' among several other topics (Physical Sciences PS 2A through PS 3D). Because these topics involve energy (force divided by time), force is fundamental, and because force is mass times acceleration, acceleration is fundamental to nearly all topics in a physics curriculum. Therefore, kinematics should come first, and it may even come before the study of chemistry. (Some researchers have gone a step farther and believe that physics should precede all the other sciences;[6] however, that debate is beyond the scope of this investigation). Kinematics comes first in most physics curricula.

Misconceptions of Kinematics Concepts May Be Common Among Physics Students The problem of university students' inability to answer kinematics questions has been introduced above. Why these students give incorrect answers to questions which professors have deemed too easy for university-level students is the subject of the following analysis. Because of the variety of reliable kinematics tests which consistently confound university physics students, the problem seems not to be with how the tests are written or administered. Two important pieces of evidence suggest that the problem may center with the student's preconceived notions of how phenomena in the natural world behave. **Students enter university classes unable to understand kinematics concepts**

The blame for the lack of or impermanence of student learning in high school and college physics is usually assigned to the teacher or the professor. However, the teacher or professor often does not know how to help the student to 'un-learn' what the student thinks he or she already knows through prior experience. The mental construct of the misconception must therefore be examined.

To understand a definition of a misconception, one must first consider the nature of learning. It is beyond the

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[5] Piaget (1946) was possibly the first researcher to consider the age of children and their conceptions of kinematics principles. Students from age 4 to age 14 used toy trains and other moving objects as they conducted scores of different kinematics studies. Data were gathered by interviewing the students as they observed the various motions, usually of two objects moving on different tracks at the same time.

Although Piaget's (1946) findings are too extensive to fully review here, they can be roughly summarized. Children younger than approximately 6 years of age had some comprehension of displacement as path traveled, but almost no comprehension of speed or acceleration. Most of the younger children measured displacement by the placement of the cars—one car ahead of another meant that it had traveled farther, no matter where it started. Children 6 to 8 years old could comprehend displacement as measurable path traveled, and intuitively work with speed, but not make any formal rules about speed and time. Children of these ages could not comprehend acceleration. Children of ages 10 to 14 could make rules about speed in terms of distance and time, and some children at the age of 14 could intuitively grasp the notion of acceleration.

Dykstra and Sweet (2009) found that, of students who used RTGs to study position versus time, 4th, 6th, and 8th graders all saw significant gains on a post-test containing graphical representations of the distances and speeds, while only the 6th and 8th graders who used the RTGs improved on the when studying speed versus time. If the ages of 4th, 6th, and 8th graders are commonly 9, 11, and 13, then they would loosely confirm Piaget's (1946) findings especially when speed is considered, although Piaget (1946), unlike Dykstra and Sweet (2009) did not test the children by having them interpret graphs. Here an important qualification is apropos: Age findings are not dispositive. Indeed, Piaget (1946) noted that some of the 7-year-old students he studied were able to comprehend uniform accelerations as well as some of the 10-year-old students could (p. 274). In fact, Piaget found probabilities, rather than hard-line age rules, were the better way to measure students' facilities with certain concepts, and he lists percentages of students of certain ages who comprehended various concepts (pp. 226-227). Similarly, the NRC (2007) notes that in many areas of science, Chinese students could answer questions which American children could answer only when they were two years older than the Chinese. It is important to note that not all data that can be represented on a graph is inaccessible to students younger than the 6th grade. For example, the National Council of Teachers of Mathematics (2000) includes a graph of plant heights versus time of growth in its grades 3-5 Algebra standard. Further study of students of different ages considering different kinds of representable data is therefore warranted.

[6] For example, Bardeen and Lederman (1998) state that science text books often state prerequisites for studying the book's course, and these requirements have Physics concepts as necessary for Chemistry, and Chemistry concepts as essentials for Biology (p. 178-179). Bardeen (2002) states that the American Renaissance in Science Education (ARISE) elaborates, stating that when the Committee of Ten planned curricula in 1894, it did so with a biological science that was far more descriptive and qualitative than the life sciences are today (The State of Physics First Programs, p. 7). To follow a program that places Biology first, therefore, is to ignore the developments in over a century of the life science. Lederman (2008) states that the descriptive life sciences content is best for middle school study, and that the complex high school life sciences are best reserved for after a student has acquired facility with concepts and methods from Physics and Chemistry (p. 103). Project ARISE is fully committed to a Physics-Chemistry-Biology sequence, which is at the center of ARISE's proffered solution to the problem of student boredom and flight from the sciences (Bardeen, 2002, pp. 3-6).

scope of this literature review to develop a comprehensive definition of learning. To several well-known scholars whose work has contributed to educational research,[7] learning is a process by which the learner constructs his or her own understanding of new facts and situations by comparing his or her experience of things known to the things that are new. This definition applies to this literature review.

The heart of the problem: physics students may have and hard-to-change misconceptions of kinematics. In the studies involving students who have failed to answer kinematics questions correctly, closely examining what students in the process of answering the questions have said about them and about their approaches to solving them, has revealed that the students have misconceptions about how things work in the natural world. Trowbridge and McDermott (1980) define 'misconceptions' as 'disparate protoconcepts' that are often based in a student's informal experience and which run contrary to scientific understandings of phenomena (p. 1027). McDermott's (1990) definition of 'misconception' is a conclusion or explanation for some phenomenon that "conflicts with scientific understanding" (p. 7). In McDermott's view, the definition applies to children and adults. Another term for 'misconception' which occurs often in the literature, and which is used interchangeably here is 'naïve notions,' or 'naïve conceptions.' McCloskey (1983) states that naïve notions held by the Johns Hopkins University students he studied came from students' experiences in the physical world. In that study, physics students were found, through their answers on a qualitative kinematics test, to be thinking with a misconceived notion of force similar to the medieval impetus theory (pp. 311-313). According to Halloun and Hestenes (1985b), an enormous stumbling block to learning fundamentals of kinematics is that misconceptions block out any new ways of thinking, and are extremely difficult to dislodge (p. 1048). Similarly, Strike and Posner (1992) state that scientific misconceptions are 'highly resistant to change" (p. 153). Mestre (1994) attests to the stubbornness of misconceptions by citing the existence of an American adult citizenry whose scientific thinking is dominated by misconceptions. How to help students to change such stubbornly-held notions is crucial to science education, and is also addressed below.

'Un-Learning' Kinematics Misconceptions and Learning Kinematics Concepts Requires a Scientific Approach Graphing and graph interpretation are skills crucial to student understanding of formal kinematics concepts. Halliday et al.'s (1997) definitions of displacement, speed, velocity, and acceleration, discussed above, are all accompanied by graphs that represent the concepts. The first chapter or two of any high school or college physics text or curriculum materials reveals to physics students that physicists speak not only in formulae, but also in graphs. To address the role graphing plays in students' learning of physics first requires an exploration of science and scientific methodology.

Nature of scientific methodology and the role of prediction According to Driver, Leach, Millar, and Scott (1996), "[t]he purpose of science is to produce viable explanations for phenomena" (p. 144). Driver, et al. (1996) add that any explanations should go beyond the observations (p. 145). The NRC (2007) adds that science involves a process of logical thinking through which theories are built and changed (p. 175). Derry (1999) states that science is "starting with ideas and concepts you (*sic*) know, observing the world, trying different things, creating a coherent context, seeing patterns, formulating hypotheses and predictions, [and] finding the limits where your (*sic*) understanding fails…" (pp. 303-304). Hempel (1966) states that falsification of theories (proving a theory false by showing that the theory cannot explain all cases of like phenomena) is at the center of scientific exploration, and applies to hypotheses and theories popular in scientific communities. Driver, et al. (1996) state that explanations "involve imagination… (and)…do not 'emerge' from the data" (p. 145). The NRC (2001) adds that "reading beyond the data requires students to make predictions or inferences from the data that are neither explicitly nor implicitly stated in the visual representation (p. 290). Indeed, according to Schwab (1962), science is a verb: theories are not settled, but sci-

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[7] According to Piaget (1950), a person learns when facing the choice of whether to change his or her thinking to accommodate new situations, or else to change the situations to match his or her thinking. Piaget calls these two processes assimilation (the new information was incorporated into the learner's existing thinking) (pp. 8-9) and accommodation (the learner changed his or her existing thinking to meet the new situation) (pp. 9-10). To Piaget, the learner constantly needs to choose between accommodation and assimilation, a process which Piaget calls equilibration (pp. 16-18). As such, Piaget believes that the human being constructed his or her own knowledge on his or her choices of how to face new information. Piaget's understanding of human knowledge, then, involves a process of knowing.

To Bruner (1960), learning is a process that involved the student's active, self-initiated exploration of any subject or phenomenon. Sandoval (2005) also asserts that learning in science is a process of asking questions, generating data, interpreting the data, experimenting with new data, evaluating, and arriving at a conclusion. As such, to Sandoval, learning was a process, rather than a product. Gagne (1963) likewise sees learning as a process by which a student's understanding moved through a well-ordered hierarchy of information, beginning at the most basic skills and information, and advancing with experience to more complex skills and situations.

entists are constantly creating and re-creating them (pp. 56-57). Kuhn (1962) and Popper (1957 and 1970) have written extensively on the nature of how scientific communities change scientific paradigms. Their debate is beyond the scope of this review,[8] but to both researchers, an element important to changing scientific ideas is making predictions based on theories and subsequently testing the predictions through experimentation. The Popper versus Kuhn debate has implications for how researchers understand concept change to occur, and is addressed below.

Students in inquiry-based science labs test their ideas about how certain phenomena work. Linn and Songer (1993) state that lab experiments give students observations on which to base and evaluate predictions. Beichner (1996) and Hennessey (1999) both note that prediction is crucial to scientific thought. In its Physical Science Core Idea, the NRC (2011) emphasizes prediction in its standards for all age groups. Such hypothesizing, testing, and collaborating is at the heart of scientific thinking, and the NRC wants students to engage prediction as early and often as is possible.

Student misconceptions of the study of kinematics and scientific methodology. Students often misconstrue the purposes of scientific study, and many of their misconceptions prevent them from understanding or practicing scientific methodology. For instance, Strike and Posner (1992) reported than many college students whom they surveyed with qualitative questioning believed that the reason to study physics is to get correct answers on physics tests and problem sets (p. 163). Dole and Sinatra (1998) found that students are often reluctant to challenge a theory or prediction because they are taught to first be skeptical of the data (p. 125). Dole and Sinatra conclude that when students are told to challenge data before challenging theory, the assumption is that the theory is immutable, misconception which runs contrary to the tentative nature of scientific theory.

The crucial role graphing plays in evaluating scientific predictions. Predictions are meaningless if they are not tested and the results evaluated. One of the strongest justifications for using RTGs in school kinematics labs, discussed fully below, has been that their use allows students to run many prediction tests in little time. As many researchers, including Thornton and Sokoloff (1990) have stated, the RTGs graph the event instantly and save students from the time-consuming chore of setting up the axes and plotting all the points (p. 866). Many studies, some of which are reviewed in Strand II below, have stated that allowing students to ask 'what if' questions and to test them instantly on the computer program is crucial to their effectiveness at helping students to learn the concepts. Several researchers have hinted at why RTGs may be helpful. For example, Tall (1996) stated that students in his study overwhelmingly preferred graphs over tables of numbers, and hence graphs help to improve their attitudes towards studying science (p. 302). McDermott, Rosenquist, and van Zee (1986) add that the graph is where students can see the information well enough to compare it to expectations, thereby evaluating their predictions (p. 513). Beichner (1994) explains that "A graph depicting a physical event allows for a glimpse of trends which cannot easily be recognized in a table of the same data" (p. 750). Beichner adds that the availability of graphs allows students to observe even subtle changes that result from students' manipulations of variables. Trumper (2003) states that "students can predict results in terms of graphs…and if there is a disagreement between the graphs of observations and predictions, students must…make the required adjustments in either the experiment or the prediction on the basis of the graphic information (p. 661). Trumper's (2003) view therefore closely parallels the general nature of scientific thinking. The NRC (2011) likewise has stated that students should use graphs to test and check for wrong data or predictions (Science and Engineering Practices). Trumper (1997) adds that a graph is a tool for predicting the relationships between variables and to "substantiate the nature of the relationships" (p. 93).

Mathematics education researchers have commented on the importance of representation in math and science.[9] Heid (1997) states that graphing programs of all sorts had great potential to help students to learn mathematics concepts because of how they made large sets of data conveniently visible to students (pp. 7-8). Heid's study cited graphing calculators, interactive videos, and micro-computer based labs (MLB's) as resources with the greatest potential to render the abstract visible. Heid noted that with many of these computer programs, students could ask their own questions and get instant, visual feedback. Glazier

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[8] Kuhn (1962) states, generally, that theories are built and changed through revolutionary changes of thinking among members of a scientific community. To Kuhn, scientific theories and paradigms might be settled temporarily, with one paradigm in the ascendancy, but some new and improved way of viewing phenomena or experimenting inevitably adds unexplained phenomena to the data set, forcing scientists to either expand the old theory, or else to replacing it with a new one. Popper (1970) agrees in part with Kuhn, stating that science is a process of reworking ideas, but disagrees with Kuhn's notion that one paradigm is ascendant (pp. 54-55). Popper (1970) states that changes in scientific ideas occur through an ongoing contest among concurrent ideas competing to explain the same phenomena (pp. 54-55). Popper (1957) also disagrees with Kuhn in that Popper held that idea changes do not occur in great upheavals, but rather through gradual evolution that occurs by testing and re-testing theories (p. 203).

[9] See footnote next page

(2011) stated a similar idea far more simply by noting that a graph can say efficiently what might take thousands of words of text or teacher lecture to accomplish (p. 189). According to physics educators such as Trumper and Gelbman (2002), the graph, then, is the main tool by which the RTG works—the graph evolves rapidly as each successive experiment is run (p. 217). In other words, the graph is where students can see the results of the tests of their predictions. If a machine produces the graph quickly, then the machine may help that student to practice scientific work more often in the same amount of time than the student may be able to do without the machine.

Graphing and graph interpretation skills physics students need. As was noted above, to study physics, students must comprehend kinematics concepts. In addition, the use of graphs is essential to evaluating predictions of measurable kinematics phenomena. Indeed, the NRC (2011) states that graphing is a means of discovering errors in data (Science and Engineering Practice). In defining kinematics terms, Haliday et al. (1997) referred to displacement-versus-time, speed-versus-time, and acceleration-versus-time graphs as illustrations (pp. 13-17). Halliday et al. (1997) and countless other physics curriculum writers have implied by using graphs as illustrations that reading axes, ordered pairs, and slopes is a 'given' when studying high school and college physics. Several national research bodies have made general recommendations for using graphs in school math and science curricula. It is important to note that these bodies see graphing and graph interpretation as skills important to students of all ages.[10]

Student problems with graphing. In the face of all the standards and recommendations that call for students to be able to read the axes, the data, and the mathematical relationships on graphs in order to evaluate predictions are legions of students who do not know how to read even the most basic linear graphs. Researchers have stated generally that students do not understand the data that is represented on graphs.[11] Confusion over slope and height is a particularly important problem in learning kinematics. Both Rosenquist and McDermott (1987, p. 409) and Trowbridge and McDermott (1980, pp. 1022-1023) describe a prosaic example of slope-height confusion: students examine a position-versus-time graph of two objects moving at different steady speeds, where one object overtakes the other. On the graph, the moment at which one object overtakes the other is represented by an intersection of the two lines. Students

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[9] Mathematics educators have made many contributions to the ongoing conversation on graphing and RTGs in science education, some of which help to explain why graphing may help students to recognize changes better than when using tables of numbers. For instance, the NCTM's (2000) states that graphing technologies can allow students to see many more examples of visual models of phenomena than would be possible if the students were forced to draw the graphs by hand (Technology Principle). In noting that students could focus on more advanced concepts when the tedium of plotting points was removed, the NCTM adds that graphing applications such as calculators and RTGs are key elements to reducing the drudgery. Implied in the NCTM's position is that representation is the act of making the abstract visible. In addition, several of the NCTM's (2000) standards advocate the use of representations of physical phenomena while teaching mathematics. For example, the NCTM (2000) provides an example of a temperature graph heavily annotated with hand writing that states the physical events which corresponded to graph's salient points (Representation Standard for grades 9-12).

[10] According to the NRC (2007), mathematics and science are admittedly separate academic disciplines, but for doing scientific analysis, school students of all ages must use and practice mathematics skills, including working on a Cartesian plane (pp. 153-154). The NCTM (2000) has presented an extensive treatment of how students of various ages should work with graphing: Students in grades 3-5, for example, should be able to represent simple number patterns and functions with words, tables and graphs. Students in grades 6-8 should be able to represent and graph data and identify graphed functions as linear and non-linear. In addition, these students should be able to model physical, social, and mathematical phenomena. The National Assessment Governing Board (NAGB) (2010 Math) states that students of all ages should be able to graph real-world phenomena, including, for 8th graders, linear relationships, and for 12th graders linear, parabolic, hyperbolic, logarithmic, and trigonometric relationships (p. 33). The NCTM (2000) has given examples of the linear graphs which 8th grade students should be able to interpret, and for 12th graders includes interpreting linear, parabolic, and hyperbolic functions, and using such graphs to determine rates of change.

[11] For example, Nachmias and Linn (1987) report that high school physics students were unable to determine the meaning of a temperature graph, and this rendered them unable to spot the unreliable data (p. 499). Leach, Hammelev, Miller, Niedderer, Ryder, and Tselfes (2000) report that high school kinematics students did not know why they needed the data, much less whether the data were accurate. Hennessey (1999) reports that high school kinematics students did not know the meaning of position or velocity versus time graphs (p. 24). Glazer (2011), provides an excellent metacognitive study of teacher and student problems with graphs and graphing. Her examples of problems are more specific, and include confusion of slope versus height, point versus interval, graph as a picture, and graph as a set of points contribute to poor graph interpretation (p. 195). Lesser interpretation troubles include color, size, and exaggeration in the x and y axis (p. 199). Many math and science educational studies have confirmed Glazer's (2011) analysis. For example, Brassell (1987), Linn, Layman, and Nachmias (1987), Mokros and Tinker (1987), Beichner (1993), Lapp (1999), Lapp and Cyrus (2000), and Botzer and Yerushalmy (2008) all have found that middle school and high school students have tended to view graphs as pictures of the motion track of the object, rather than the speed or position being represented. For instance, students observing a speed versus time graph of a ball rolling down a hill might choose to match it with a linear graph with a negative slope because the graph looks like the hill down which the ball rolled.

asked whether the objects are ever moving at the same speed often state that the intersect point of the two position-versus-time lines represents the instant when the speeds are the same, even though that point represents when the positions are the same—the speeds are never the same, and the slope of each line confirms this only if the student understands. Trowbridge and McDermott (1981) describe a similar slope-height confusion, this time when two straight lines on a velocity versus time graph intersect. Students are asked when the accelerations are the same, and they wrongly pick the intersect point instead of using the slopes (p. 243). Additional graph interpretation problems occur when students cannot determine the slope of the line if the line does not pass through the graph's origin (McDermott, Rosenquist, and van Zee, 1986, p. 504, and Beichner, 1994, p. 754), and when students cannot even draw the graph of the line if it does not pass through the origin (McDermott, et al., 1994, p. 510). *'Thingification' of graphs.* A specific problem students have with graphing is the tendency to regard the graphed data as pictures that represent objects or paths traveled by moving objects, rather than representing the abstract relationships among the data points or axes. Studies where students have mistaken the shape of a graph for the physical appearance of the path the object traveled are legion. For example, if a student saw a ball rolling down a steep hill, steadily picking up speed as it rolls, the student may think that the ball's velocity-versus-time graph should resemble the downhill slope on which the ball traveled, rather than a line with a positive slope, as the ball's velocity is increasing as it rolls.

Russell, Lucas, and McRobbie (2004) noted that when students discussed graphs, they sometimes focused on their shape, a development which the educators found encouraging, but that the students also talked about the graphs as though they were things with concurrent shapes, which was not desired (pp. 172-173). The AAAS (2009) seems to have joined the students by declaring that lines are "things!" (Math Inquiry Standards). 'Thingification' is not a word, but several researchers, including Leach (2006, p. 7, quoting Desauteles and LaRochelle (1998)) have used the term in discussing the tendency of adolescent science students to objectify abstract concepts including data represented on graphs. As such, 'thingification' of graphs and science concepts is a misconception which the use of RTGs may proliferate if teachers are not wary. The RTGs function, after all, is to represent data as visual graphs, all of which have some sort of shape. Beichner (1994) points out an important danger with thinking of graphs as things: He notes that when students believe that a graph is a picture of a thing, they are less likely to believe that there is viability in changing something (the graph) which is already fixed (p. 754).

MISCONCEPTIONS ARE CANDIDATES FOR CONCEPT CHANGE

According to Strike and Posner (1992), "novice learners do not approach learning with blank slates. They approach new ideas with prior conceptions that govern their interactions with them" (p. 152). Scores of other researchers have reported similar observations about students. The misconceptions discussed so far about kinematics concepts, the nature of scientific methodology, and the reading and interpreting of graphs are obstacles to students' learning of kinematics principles. Strike and Posner (1992) state that misconceptions are highly resistant to change; yet misconceptions such as those discussed above are exactly the sorts of ideas that "may become candidate[s] for change" (p. 153) before physics students can learn kinematics principles. The goal is not solely to give students new information; the goal is to help students to change what they think about the way things move and how to represent motion mathematically.

Traditional Methods of Instruction Usually Fail To Change Student Concepts. Even at the college level, traditional methods of instruction (defined here as lecture-demonstration and cookbook-style confirmation lab exercises) do not seem to be effective at helping students to learn to interpret graphs. For example, Halloun and Hestenes (1985b) found that even after a full semester of university kinematics instruction, one third of students were still missing questions asking students to interpret graphs of motion (p. 1048). Champagne, Klopfer, and Anderson (1980) reported that there was no observable (through analysis of a pre-test for a university physics course) advantage for university physics students who had taken high school physics when compared to students who had never taken high school physics (p. 1076). Whether students have taken high school or college physics, their misconceptions about motion, force, and graph interpretation have persisted. The question therefore is whether there are ways to help students to re-arrange their thinking about kinematics concepts.

When Educators Help Students To Think Scientifically, Students' Concepts May Change. In attempting to create new strategies to help students to learn new concepts, some researchers have sought historical guidance from instances which have demonstrated how scientific communities have changed scientific theories, with the notion that what may work for a scientific community might work for the individual.

Perhaps the best-known example of this type of research has been Posner, Strike, Hewson, and Hertzog's (1982) work, which compared concept change in the individual with the scientific revolutions described by Kuhn (1962) (p. 212). In their theoretical work, Posner et al.

(1982) identified the problem: the existence of well-articulated misconceptions in students' minds that are difficult to explain away through instruction (pp. 213-214). Solving the problem requires the student to either assimilate or accommodate the new idea, depending on the degree of clarity with which the old idea is articulated—assimilation may be used when the student's initial idea is clear, and accommodation when the student's initial idea is unclear (p. 213). The four mental conditions necessary for concept change are paraphrased here as 1) dissatisfaction with the current concept; 2) the existence of an intelligible new concept; 3) initial plausibility of the new concept; and 4) the new concept allows for fruitful research (p. 214). Posner, et al. (1982) believe that concept change is difficult, and could occur only teachers carefully designed curricula that placed students into cognitive conflict (pp. 224-225). Hundreds of subsequent researchers, including Strike and Posner (1992) have investigated the Posner, et al. (1982) theory, both reflecting upon and elaborating upon their (1982) work.

Seyedmonir (2000) for example, states that students begin their formal study of science with naïve theories, which they elaborate and revise repeatedly (p. 19). The NRC (2007), has identified three types of concept change as 1) "elaborating on existing conceptual structure," 2) "restructuring a network of concepts," and 3) "adding new (deeper) levels of explanation (pp. 107-109). These types of change all assume that the learner already has ideas, but how to change the ideas depends largely on how well the learner has articulated them to him or herself. Hestenes, et al. (1992) appears to agree with Posner, et al. (1982) in stating that only when a new idea structure is introduced is it possible to change an existing concept (p. 154).

Strike and Posner (1992) qualify the Posner et al. (1982) theory, by stating that student misconceptions are often not well-articulated (p. 156), and that even when students' miscon- ceptions are well-articulated, such entities of thought rarely rise to the level of symbolic articulation found in scientific theories (p. 158). Strike and Posner (1992) thus retreat slightly from their initial comparison of the 1982 theory to Kuhn's (1962) theory of scientific revolutions.

Indeed, there has been some debate over how well students articulate or understand misconceptions. Ozdemir and Clark (2007) have identified the two main possibilities as either 1) when the student carries a highly structured understanding of some phenomenon, called "knowledge-as-theory," (p. 352), or 2) when the student carries a poorly structured collection of observations or ideas that explain phenomena in a vague way, known as "knowledge-as-elements" (p. 354). Indeed, researchers have observed different degrees of structure in student thinking. For instance, Champaign, et al. (1980) assumed that the stubbornness of misperceptions to change was proof of their level of sophistication (p. 1072). McCloskey (1983) stated that students' scientific theories were always well articulated, and this high degree of articulation was reflected in the way students could relate them to everyday experiences (p. 299). Other researchers have found that student misconceptions have been poorly articulated. For example, Halloun and Hestenes (1985a) stated that, "the conceptual systems of the students have much less internal coherence than the Aristotelian and impetus systems. They can best be described as bundles of loosely related and sometimes inconsistent concepts" (p. 1058). Trowbridge and McDermott (1980) stated that the university physics students they studied had a "wide array of vague and undifferentiated ideas about motion based on intuition" (p. 1020).

The debate over how well articulated student misconceptions are runs parallel to the Kuhn-Popper debate over how scientific ideas change. Kuhn (1962) believed that most physical phenomena were explained by one well-articulated theory that a new and more comprehensive theory had to topple, while Popper (1970) believed that scientific phenomena typically had several concurrent theories trying to explain them. The debate also has implications for school kinematics learning. If student ideas are well formed, then helping students to change them may be more difficult than if the ideas are poorly formed. However, in both cases, student experience at predicting, testing, and evaluating seems to be a most likely means to change misconceptions.

Dole and Sinatra (1998) have created a concept change theory from what they called a "cognitive constructivist perspective" (p. 110). This theory states that the mind and attitude of the student are at least as important to concept change as the nature of the scientific ideas being considered (pp. 111-112). To Dole and Sinatra (1998), the student's ability and motivation are what cause the student to add to what he or she already knows, and are therefore what drives the change in a student's conception of a phenomenon (p. 116). Dole and Sinatra take the position that concept change is an evolutionary, rather than a revolutionary process.

Some researchers appear to agree with the Dole and Sinatra (1998) understanding of how concept change works. For example, Trumper (2003) stated that when students have ideas that are at odds with scientific concepts, the goal should not be to replace the students' ideas, but rather to modify them (p. 650). Seyedmonir (2000) believes that concept change occurs either through abandonment or revision of student ideas, not simply by adding new ideas of information (p. 20). Similarly, Ozdemir and Clark (2007) state that "the process of learning [is] a gradual re-crafting of existing knowledge that, despite many intermediate difficulties, is eventually successful" (p. 358).

However, in comparing approaches to concept change, Ozdemir and Clark (2007) have found that all proceed from the observations that informal (or naïve) thinking affects later formal thinking, that much naïve thinking rejects change, but that experimentation ought to be used to create new conceptual knowledge (p. 355).

Concept change as a kind of scientific pursuit. Because the idea of concept-change runs parallel to the idea of large scale changes in scientific ideas, it should come as little surprise that the methods researchers discuss when recommending programs for student study often reflect scientific methodology. Scientific methodology always includes observation. Indeed, when the NRC (2007) discusses how students might experience Newton's Third Law, the recommendation is not to use a balance or a table, but rather for the student to stretch out an arm and hold a book up with the arm horizontally extended (p. 115). Lederman (2004) adds that students need experience to analyze, and on which to reflect (p. 309). Of course, observation is not the only element to scientific methodology. Analysis and prediction, discussed above, are also vital. Trumper (2003) states that the physics laboratory is for the development of skills, concepts, nature of science, and attitudes needed for scientific inquiry (p. 646). How to run a lab is worthy of brief exploration.

Guided Inquiry-Based Learning: Where to practice concept change. How scientific methodology should be manifest in classrooms has been the subject of intense debate for decades. A full discussion of that debate is beyond the scope of this review;[12] however, an institution of school science which has fallen under heavy scrutiny has been the verification, or 'cookbook' lab exercise, where students do a step-by-step process at the direction of the teacher to try to verify an already-studied scientific principle. If concept change requires students to feel some discomfort with their own ideas, then a cookbook style lab may not serve as a concept changer.

According to Trumper (2003), scientific knowledge cannot be handed to students, but must be constructed by students through the same sort of challenging and uncomfortable situations which Posner, et al. (1982) mentioned (pp. 650-651). According to Hofstein and Lunetta (2003), students are best engaged by open-ended inquiries, rather than cookbook style laboratories (p. 38). Allchin (2000) stated the when learning through lab work or through the history of science, students should be shown the messiness of science, and should not be given labs in neat packages that make the outcome appear inevitable (p. 34).

Many science educators now believe that guided inquiries are a preferable means to give students challenging situations for investigating kinematics concepts. Guided inquiries occur when the teacher sets the subject and objectives of the lab, but structures the investigation so that students may invent their own questions about the subject which they may immediately test using various lab equipment, including RTGs. An example of a guided investigation is using motion sensors to measure the effect of forces on carts on a track. The teacher may instruct the students to measure the speeds of the cart when pushed with forces of varying strength, but leave it up to the students how hard to push, how to measure the strength of the push, and how many trials to run. In such a case, the teacher has set the objectives, but has left parts of the inquiry up to the students. For students to test their own hypotheses requires

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[12] The nature of the debate has been how much direction lab students should receive from teachers or textbooks. Adherents of the 'pure discovery' school of thought, including Bruner (1960) and Schwab (1962) have said that students should explore phenomena with little or no direction, and should develop their own questions as they go. Adherents of a more rigid, teacher-directed school of thought, which may include Gagne (1963), have said that pure discovery would force students to learn a vast volume of science with no direction, and that students could therefore never master such content. In advocating a 'guided discovery' approach, Ausubel (1964) recognizes that efficiency was needed to apprehend 5,000 years of science learning, but that students had to construct their own ideas as they went.

As a result of the debate and the apparent ascendency of guided discovery, the term 'discovery' has largely vanished from scientific education literature. The new term is inquiry-based learning. The idea of inquiry-based learning is very similar to discovery learning, in that students ought to ask many of the questions, and ought to be able to invent ways to investigate them; however, inquiry-based learning assumes that there is a curriculum that contains some guidance and content standards.

According to the AAAS (2009), science teaching in American schools must feature inquiry-based, student-centered instruction. An environment that supports inquiry affords students opportunities to test their intuitions, to invent experiments, to think, and to predict. The AAAS is not alone in supporting inquiry-based learning in the science classroom. The NAGB (2010), while giving scientific content top priority, states that inquiry is vital to student learning. According to the NAGB, inquiry includes the ability to conduct scientific investigations using appropriate tools and techniques, while searching for patterns in the data and comparing such patterns to theoretical models. The NRC (1996) has stated that inquiry applies not only to student learning, but to teaching standards, professional development, and science content, which includes unifying concepts, inquiry, and content from the various scientific disciplines. According to the NRC (1996), inquiry includes guided discovery, assessment of that discovery, and work in communities of learners. These three national bodies seem to recognize the importance of balancing discovery with learning content, and of discovering scientific principles and phenomena through teacher guidance.

Rivers and Vockell (1987) studied high school student work on a biology simulation program that allowed students varying amounts of teacher guidance in their computerized discovery of biology. This study found that students who proceeded with the least guidance performed the best on post-tests (pp. 408-409).

them to have tools that allow tests to be done efficiently during the limited time of a science class. In fact, Novak and Krajick (2004) have stated that the definition of educational technology is those tools which allow students to ask and test their own 'what if' questions (p. 76). As noted above, one of the strongest assets of RTGs is that they allow many quick tests to occur in little time. The student makes the prediction, and tests it, and the RTG produces the graph which allows the student to see immediately the results of the test and the viability of the prediction. Trumper and Gelbman (2002) state that inquiry labs must not only be hands-on, but also 'brain on,' to be effective at helping students to learn physics (p. 211). The RTG may be the right tool for engaging the brain by providing the visual data. That, anyway, is the theory of it.

SUMMARY: STRAND I

This section has developed the idea that kinematics is fundamental to the study of physics and maybe even the other sciences. To learn kinematics concepts requires students not only to hear lectures and see demonstrations of the principles, but also to predict outcomes based on the concepts, to test their predictions, and to evaluate the results. Creating and interpreting graphs is crucial to the predicting, testing, and evaluating process, and understanding the concepts and relationships that the graphs can represent is likewise critically important. When students are engaged in predicting, testing, and evaluating their ideas, they are practicing scientific methodology. Such a methodology appears to be effective at helping students to either set aside, or else to modify their misconceptions sufficiently to learn kinematics concepts. Whether and how RTGs can be effective tools for such a methodology is the topic of Strand II.

STRAND II

Can RTGs Help Students to Experience Scientific Methodology if Delays Occur? Assuming Posner, et al.'s (1982) list of four conditions necessary to promote concept change, discussed above, is reasonably 'accurate,' the main question in this Strand is whether RTGs have been observed to help to create or promote such conditions. Therefore, references to Posner, et al.'s (1982) conditions ('Posner's Conditions') occur in the discussion that follows. For the purpose of this literature review, 'educational technology' means any electronic devices used as part of classroom, laboratory, or field trip instruction, including presentation hardware. 'Probeware,' are sensors that directly measure physical and life properties such as temperature, salinity, and motion, and through connection to a computer, produce graphs of the data. RTGs are probeware which produce graphs instantly, so the student can view them in the same instant in which they are observing the phenomena.

This literature review focuses on RTGs used in kinematics classes. However, studies of many applications that were neither real-time nor concerned with kinematics have revealed principles that apply to RTG use with kinematics, and are therefore considered here also.

Assessing Student Learning with RTGs This literature review first considers studies that examine outcomes of treatments using RTGs, mainly with kinematics students. Such studies have often used pre-post testing to measure the outcomes. Next considered is qualitative evidence from lab technology studies. Here, the question is how students are thinking in the actual moments during which they are using the RTGs. Finally, qualitative studies that have recorded student thinking during the use of electronic games, simulations, and other technologies are examined. These studies indicate ways in which many technologies may be used to better engage students in scientific thinking and action, and may help to shed light on whether the *time* in Brassell's (1987) assertion is crucial, or whether student thinking during delays can play an overriding role.

OUTCOME-BASED STUDIES

Brassell (1987) is but one researcher who has found higher kinematics post-test scores for high school kinematics RTG users than for RTG non-users. Kozhevnikov and Thornton's (2006) one-semester study of college introductory kinematics students shows that after using RTGs, students initially assessed as strong at visual and spatial ability were observed to lose their initial advantage to students who had been assessed as weak in those same abilities. Pre- and post-testing in that study revealed that RTG users weak at visual and spatial abilities improved more than those who did not use the RTGs. Thornton and Sokoloff (1990) and Sokoloff, Laws, and Thornton (2007) each have found that students using RTGs instead of going to lectures made far fewer errors on post-test kinematics questions than students who had gone to lectures instead of using RTGs. In addition to these studies and those cited in the general introduction above, many other studies indicating encouraging results have been published; however, the reasons for student success have been either speculative or unclear. For example, Struck and Yerrick (2010) found strong gains for students using RTGs in kinematics (pp. 203-206), but admit to being unable to pinpoint the causes of the improvements (p. 207). Brungardt and Zollman (1995) speculate that kinesthetic movement by the student might be important to his or her experience (p. 867). In that study, students watched videotapes of motion and real-time graph production, but on post-testing, these students showed no improvement.

Still other studies have produced mixed results. For instance, Zucker, Mansfield, Metcalf, Strandt, and Tinker (2008) found that kinematics and pre-kinematics students from grades 3 through 8 produced significant improvements on the overall post-tests, but there were several kinematics areas, such as speed versus time, in which the students failed to improve at all (p. 47). Of course, Dykstra and Sweet's (2009) finding that students younger than 6th grade were generally incapable of comprehending speed versus time graphs may explain the inconsistency pp. 8-9, 20-21). Adams and Shrum (1988) found that RTGs helped high school students to interpret graphs, but the same students could not by pencil and paper draw even the axes of these graphs (pp. 19-21). The inability to produce or even identify the units on the graphs' axes indicates a lack of understanding of the information on the graphs (pp. 25-26).

Although there have been many studies indicating that using RTGs correlates positively with increased student performance, some of the results must be taken with a grain of skepticism. A shortcoming of outcome-based results is that they do not indicate student thinking during the activity studied, and therefore reveal little directly about the students' scientific ideas. By examining real-time motion programs in real-time classes, qualitative researchers have uncovered results that help to explain how the RTGs may help students to think as scientists.

Real-time qualitative assessments of students in RTG-based labs. There are three most oft-cited explanations for the effectiveness of RTGs in fostering students' scientific thinking. These are, 1) that it forces students to interact with the data in the form of student-generated 'what if' questions and tests of those questions; 2) that it pairs physical actions of students with the graphs; and 3) that it reduces cognitive load. These three types of explanations speak to Posner's Conditions, as well. When students ask 'what if' questions, for example, they think they know the outcome, but the RTG may show a surprise instead. Experience with predicting and testing is likely to produce the discomfort, intelligibility, plausibility, and fruitful research which Posner, et al. (1982) discuss.

Student interactions with data and hypotheses via the 'what-if' questions and tests. The importance of prediction and testing has been reviewed above—it is at the heart of scientific work. Observing students in the midst of such work can provide useful insights into whether the RTGs are helping them to learn in the moment. Mokros and Tinker (1987) interviewed middle school students as they conducted kinematics experiments with RTGs. They noticed that students were on task when they were forced to ask 'what if' questions and run these tests through the RTG program. Students receiving instant corrections to their hypotheses were observed to comment intelligently in terms of the concepts being studied. Similarly, Kuech and Lunetta's (2002) study of college physics students found that when asking 'what if' questions in the moment, those students were heard to comment on the difficulty of concepts and to ask questions relevant to such concepts. Hennessey (1999) noticed that students studying kinematics with RTGs often asked 'what if' questions in ways that allowed teachers to discern that the students did not know what the graphs meant, or how these graphs related to the data (p. 14). In that study, the RTGs showed where student thinking was deficient (pp. 23-28). Russell, et al. (2001) note that of 27 high school students using RTGs, 26 of them directly connected the observations to the graphs (pp. 168-169).

In these four studies, classes were recorded and students' speech was analyzed. These studies did not prove that asking 'what if' questions and testing them on RTGs correlated to improvements in learning; however, they showed that much of the students' real-time thinking was relevant to the graphs and the kinematics being studied. As such, the observations suggest that RTGs may help students to think scientifically be giving them a visible manifestation which encourages them to ask many questions and to get fast answers to their hypothetical queries.

Pairing student physical motion to graphs of that motion. Something closer to an explanation for how RTGs may help students to learn kinematics may be found in studies that involve students forced to move their bodies as part of the RTG experiment. These studies are similar to several mathematics studies involving graphing. Beichner (1990) found that when students watched videos of motion and RTG graphs of the video-taped motion, their performance on the kinematics post-test did not improve. However, when students moved their bodies to create the motion which the RTG was graphing in real-time, then the students experienced significant gains in post-test results (pp. 812-813). Russell et al. (2004) likewise showed that when students moved, they talked about connections between the motion and the graphs from the RTGs. Similarly, Mokros and Tinker (1987) heard students to refer to places on the graphs as times when they had slowed down and sped up, which indicated that they were comparing their motion and the corresponding graph. Hwang and Kim's (2010) study of engineering students may not apply to high school students; yet that study found that students who gestured with their bodies engaged the kinematics labs with far more interest (as ascertained from a post-activity survey) than those who simply pushed buttons on a computer (p. 556). The Hwang and Kim (2010) study is similar to the qualitative study by Botzer and Verushalmy (2008) of high school mathematics students using motion to learn graphing principles. In that study, student hand gestures were closely watched and recorded, along with what students were saying as they moved their hands. In many cases, students used hands to map out or imitate motion in the air and also to attempt to draw the graphs in the air. Even though students were not always accurate in their graphing, Botzer and Verushalmy (2008) concluded that hand gesturing was crucial to their learning the concept of function (p. 132).

The Botzer and Verushalmy (2008) study is included here because it introduces the idea that connecting physical motion to RTG graphing might not merely correlate to student learning; but rather that that connection might serve as an explanation for why students using RTGs may learn math and science concepts.

Lindwall and Lindstrom (1999) studied high school junior physics students, whose conversations during the lab were recorded and analyzed. In that study, students who moved were heard to collaborate, predict, and evaluate, and used their hands and bodies to illustrate their points (pp. 5-8). Although that study did not generate a post-test outcome, it illustrated in real-time how students using RTGs were thinking about science (p. 15). The engaged and focused participation of students in studies where their own movements were graphed and analyzed may serve as part of an explanation as to why RTGs seem to help students to engage in scientific thinking, and may guide teachers on days when the RTG breaks down in the middle of the experiment.

Decreasing cognitive load. Although it is probably not possible directly to measure cognitive load in students, many educational researchers have suggested that an RTG-induced decrease in cognitive load explains how these tools help students to learn kinematics. According to Roschelle and Singleton (2008), the idea is that when cognitive load decreases, student thinking about higher ordered scientific ideas, such as kinematics concepts, increases and vice versa. This idea might apply to kinematics activities in that when students are forced to plot points, every point involves decisions about locating the point of the x-axis and the y-axis, plus thinking about each point's relationship to other points. As Kazhevnikov and Thornton (2006) asserted, RTGs, create a single lump of information, a graph, which students can review as a single entity, rather than as an enormous set of entities (points), freeing the student's mind to consider kinematics principles in lieu of having to remember all the relationships among the points. In making the case that graphs 'chunk' the data, Larkin, McDermott, Simon, and Simon (1980) compare graphing to chess playing. In their comparison, they say that expert chess players can look briefly at a game in progress and recall where up to 25 pieces are. However, if the chess pieces are distributed randomly on the board, the chess experts cannot recall the placement of even 10 to 15 pieces (pp. 1336-1337). Larkin, et al. (1980) explain that to the expert chess player, when the pieces are set up as part of a game, the pieces represent one chunk of information for the expert, much as a graph represents a chunk of information, where a table of data would represent many individual pieces of information (pp. 1337-1339). Hence a graph is easier to recall as a representation of data. Brassell (1987), Linn, Layman, and Nachmias (1987), Mokros and Tinker (1987) Thornton and Sokoloff (1990), Brungardt and Zollman (1995) and others have all reported that a key to how RTGs worked was to spare the student of the drudgery of plotting points. Brassell (1987), Linn, et al. (1987), and Brungardt and Zollman (1995) speculate that the real-time aspect was crucial to the effectiveness of the RTGs in that the delay would add to the student's cognitive load by forcing the student to remember what motion had produced the graph. This logical speculation strongly supports Brassell's (1987) assertion. There have been several speculations on how, beyond the reduction of drudgery of point-plotting and forgetting events that produced graphs, RTGs help students to maintain a low cognitive load. Kazhevnikov and Thornton (2006) suggest that the RTG creates a piece of information which takes up less short-term memory than an enormous set of points would take up. Bernhard (2011) builds on this suggestion by proposing the theory that RTGs give the student graphs which represent underlying concepts, but which allow students the initiative to change a variable, thereby tinkering with the concept. The importance of a data representation, discussed above, assumes great importance in a cognitive load theory. As Heid (1997) notes, when one represents data, one externalizes an abstract idea, thereby giving it a visual appearance, which may decrease cognitive load.

Connecting outcomes and real-time research observations to Brassell's assertion. The cognitive load theory is probably the strongest support for Brassell's (1987) assertion. However, real-time observations of students using RTGs have revealed that when using these tools, students are afforded the opportunity to think as scientists with computer-generated graphs as their scratch paper. Heightened engagement goes well beyond the restricted activity of trying to produce the pre-determined motion sequences described in Brassell's (1987) study. In that study, students were trying to produce correct answer—to match walking with the correct graph. In many later studies, students investigated their own questions. Students appear more interested in answering their own questions than those given them by textbooks or teachers. Where the question originates may affect the level of student engagement and achievement, and therefore needs more thorough investigation.

Principles Learned from Real-time Observations of Students Using Electronics Other than Laboratory RTGs Other than in studies of students testing their own hypotheses, discussed above, few studies of RTG use in kinematics classes have examined closely the variable of student control of the inquiry. There are many non-RTG studies that. shed equally bright light on how students think as scientists while using those tools.

Anonymity emboldens students to ask and answer questions. Kuhn (1962), Popper (1970), Hogarth (2001), and Edmund (2008) have written of the importance of intuition and cultivating intuition as scientists. One of the greatest assets that RTG and other types of technology offer to adolescent students is the opportunity to take intellectual risks. It is common knowledge that students often do not participate in classrooms when they are afraid of the ridicule of getting a wrong answer. Guthrie and Carlin (2004) note that when the college classrooms they studied were wired so that students could ask and answer questions electronically, rather than in a human voice, the participation in the classes increased significantly. Vahey, Tatar, and Roschelle (2007) found that in a high school Advanced Placement calculus class which introduced electronic, anonymous questioning and answering, not only did participation increase, but so did student achievement on quizzes and tests, even as the material got more difficult. Stroup, Ares, and Hurford (2005) theorize that chalkboards could offer students neither anonymity nor the ability to be fully interactive at all times, but educational technologies can. With the admonition that taking intellectual risks is a vital ingredient to thinking as scientists, RTGs and other classroom technologies therefore offer a pragmatic solution to a problem, student fear of participation, which has barred many students from taking intellectual risks during their classroom studies. As Ng and Nicholas (2008) report, once the participation in secondary classes is made anonymous, the students become fearless of participating and thereby engage in real-time scientific thinking.

Self-identification and collaboration in RTG labs and simulations increases student engagement. Several studies of games and simulations have shown that students who have identified strongly with their character in the simulation have tended to participate thoughtfully, helpfully, and persistently in the simulations and games. For example, Wilensky and Stroup (1999) studied students using a city traffic simulator. Each student was required to control one or more traffic signals to help avoid congestion. As the researchers gathered their field data, they heard students saying, “I am green,” or “you are red” (p. 24). Wilensky and Stroup theorize that the strong identification to role, indicated by the students’ use of the first person in speaking, kept students engaged and aware of their importance in the effort to stop congestion. Another feature of that simulation was that students coordinated their efforts with their peers. When one student in the observed group lost interest, others told him to get back in the game—that the group could not do the job without all the players. In their study of a similar simulation, Rosenbaum, Klopfer, and Perry (2006) observed high school seniors in a biology game whose goal was to stop the outbreak of a disease through quarantine. In the simulation, student played diverse professional roles, from laborer to doctor. The simulation randomly made some of the students (virtually) sick. Those who were sick often said so to one-another in the first person, thereby indicating an identification of their role. In this simulation, Rosenbaum et al. (2006) reports that students of mixed races and academic achievement thoroughly engaged the simulation and the roles, communicated with one-another, cooperated, and acted responsibly to try to prevent the spread of the disease. Even in cases where elementary school students sought anonymity and privacy, Mifsud and Morch (2007) found that they were willing to share class data with other students through communication on their handheld devices. In fact, Mifsud and Morch observed that students often initiated academic collaboration without the teachers’ requiring it. Engagement in the research process through role identification and collaboration with peers are important elements of scientific work. Academic and non-academic simulations and games, coupled with effective teaching, can help students to identify their stake in the process and to collaborate with peers. Such participation can add to the fruitfulness of prediction and testing of scientific ideas.

Student control of computer programs, simulations, and pacing is associated with student engagement of those activities. Any time a kinematics student working on an inquiry-based lab conceives a ‘what if’ question related to the lab, probeware and RTGs make quick testing of the question possible. Implied in the work of ‘what if’ questioning is that the student has some level of control over the questions being asked and how and when to test them. Rather than being given a set of progressive instructions with no detours allowed, students using RTGs can explore ideas and consequences as inspired by their own thinking.

How much control a student has over the questions asked, the speed of the lab work, and over the computer programming may help to determine how effective a learning tool the RTG or simulation is. In a non-educational article aimed at marketers, Gee (2003) reports that when designing computer games for children and adolescents, the games that were most popular were those that allowed players a choice in how the game was structured. To be a best seller, Gee states, a game must be easy to customize. Teenagers in that case are at least partially in control of the market place. If being in partial control of a game is something that helps to engage students, then finding ways to give them partial control of lab settings may be a way to increase effectiveness of RTGs in lab use.

Pedretti, Mayer-Smith, and Woodrow (1998) found that when students could set their own work pace, they were more relaxed and answered survey and interview questions with more thoroughness than when they could not control their work pace. Roschelle, Gordin, Hoadley, Means, and Pea (2000) have extended the finding of Pedretti et al. by observing that the educational technologies they were studying worked well as tutoring tools, but did not work as well as classroom teaching tools. The freedom to set one's own pace was found to be one of the contributing factors in the difference in effectiveness. In fact, Lapp (1999) indicates that the ability of students to control the RTG and probeware in science labs might be *the* dispositive variable in determining the RTGs and probeware's effectiveness as learning tools.

Clearly, seeking a balance between student control and teacher control is important.

The element of student control is therefore an important consideration. If the students cannot formulate their own questions and then use the tools to test them, then they miss an opportunity to take the academic risks which Edmund (2008) so clearly advocated, and which are so relevant to student experience with scientific thinking.

Implications for Instruction: Principles from Non-RTG Studies Which Apply to RTG Work and to Scientific Methodology in Schools. From the studies reviewed immediately above, several principles, directly applicable to student science work using RTGs, become evident. RTGs and many other educational technologies afford students space to ask and answer questions anonymously. This encourages student risk-taking, where whole-class questioning can be intimidating to adolescents. Having an identity in a simulation tends not only to give a student a personal stake in an RTG project, but a team role, also. Many RTGs and simulations can be done in small groups, and encourage data sharing. Such collaborative work is consistent with state and national science standards. Educational technologies, *especially* RTGs, give students a measure of control over the inquiry process. Such control may motivate students to engage the inquiry even more than the questions they are asking and answering. Finally, student expertise at technology is an often-untapped resource which can support RTG use in science labs, making delays less frequent, and which can facilitate student collaboration on science work.[13] For instance, when a student is a technology expert, the student may be able to suggest more efficient ways to run the lab in other lab sections on the same school day, or at very least, the next time the teacher runs the same or similar lab. Students free to ask anonymous questions and test them on the RTG may be less-likely to create their own delays because when student-initiated motion questions arise, the questions can be tested immediately instead of having to wait for the teacher or having to wait for the courage to ask the question. In addition, when a student is asking and testing 'what if' questions on an RTG, the student may immediately become aware if the RTG is malfunctioning and know to troubleshoot it quickly. Students not engaged in asking questions may be less likely to notice a malfunction, because such students are not regularly hitting 'enter' on the keyboard. One way to address Brassell's (1987) assertion is to avoid the delay altogether. All these principles provide ways to make delays less frequent. In the cases where the delays still occur, when the students are used to asking 'what if' questions, assuming roles in the assignments, and controlling the RTGs and programming, such students may be less likely to lose the RTG benefit because of a delay. Whether such ways of engaging students help students to retain the benefits of RTG usage when delays occur is not known. Further research should investigate whether using these principles help students in delay cases.

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[13] It may be common knowledge that every school has students who are experts at using technologies of all sorts. Cuban, Kirkpatrick, and Peck (2001) and Ertmer and Ottenbreit-Leftwich (2010) have warned that teachers would feel insecure in their roles as teachers as students became generally better than teachers at using technology. Even though many students have sometimes become more facile with electronics than their teachers, it is common for teachers to employ such students to help with classwork.

Cuban et al. (2001) admits that students playing the role of classroom expert often exhibited improved attitudes toward school when their role was recognized. Ringstaff, Dwyer, and Sandholtz (1991) describe a case in which a teacher reported that a student computer expert showed the teacher how to stop students from cheating by using computers, as well how to conduct successful internet research. In that case, the teacher placed the student in the unofficial role of tutor, even though that student had exhibited only average achievement in the academic subjects. Afterward, the student's academic work improved. Pedretti, et al. (1998) note that in many cases, students went for computer help first to peers, and then to the teacher only if none of the peers could help. If one of the ingredients of science literacy is collaboration and peer review, then the student technology expert who is deemed approachable by peers may be a resource available to teachers and students in science classes.

Another asset of having student experts in the classroom is that they can often troubleshoot malfunctioning electronics. In science labs using RTGs, one of the chief sources of delays of 20 seconds or more is the lack of technology staff support at the school. Having a student expert in the room can not only help to minimize delays, but can also help to keep a work group engaged, who might otherwise have given up when the sensor or RTG failed.

SUMMARY OF STRAND II

There is reason to believe that RTGs can help students to 'un-learn' kinematics misconceptions and to learn kinematics concepts. Both quantitative and qualitative measures have indicated that students using RTGs may perform better on tests, and may engage readily in scientific thought while in the lab. Whether Brassell's (1987) nullification assertion is true is not known, and demands further research. Cognitive load theory supports her assertion quite strongly. However, observations of RTG uses in and out of kinematics settings, along with observations of student uses of other educational technologies raise several researchable questions relevant to Brassell's assertion. Some of these questions are described below.

SUGGESTIONS FOR FURTHER RESEARCH

Can Brassell's Delay Be Tested? When using RTGs, some delays are inevitable. Even the most technologically-advanced students and teachers experience them. How often they occur and for how long may be an important research question.

Brassell's (1987) 20-second nullification assertion is certainly worth examining, mainly because so few educational researchers have tested it directly. In verifying Brassell's assertion, researchers must define the learning effects that may be nullified by the delays. If the effects of using RTGs are measured solely in terms of student performance on post-tests composed of multiple-choice questions on motion concepts, then delays may be a serious problem.

In addition, researchers must identify some theory that seeks to explain the resulting change in effects to the students—a mere correlation between delay and result explains very little. Further research might include metacognitive methods of helping students to connect their physical experience of the phenomenon to the resulting graph. In cases involving delays, students could engage various thought activities that may keep the memory of the event fresh, such as writing a description of what happened, hand-gesturing what happened, or making predictions as to what may happen next.

If the effects of using RTGs are measured in terms of the scientific methodology the students practice during class time, then the delays may not be a serious problem. The studies of many science educational researchers have supported the notion that the study of kinematics concepts is fundamental to physics, is an excellent venue for practicing scientific methodology. If RTG delays interfere with students' connecting any phenomenon with its graph or instantly testing their own predictions, then the delays would be an impediment to concept change in kinematics study. If, on the other hand, there are ways students work to engage scientific methodology whether there are RTG delays or not, then it may be possible for teachers and students to continue pursuing concept change even during delays. Related research questions include, first, if students using RTGs get learning benefits from using them, when do such benefits accrue—immediately or after a period of time? An answer to this question might also answer the Brassell (1987) 20-second assertion. Second, what sorts of student-generated 'what if' questions are students considering? Are there any patterns to these, and do such patterns help to shed more light on the scientific thinking of students using RTGs or the role of their control in asking such questions?

CONCLUSION

RTGs may help students to engage scientific methodology by giving them a practical tool for predicting kinematics phenomena, testing their predictions, and viewing visible representations of the abstract relationships in the data. RTGs may therefore allow students to 'un-learn' the misconceptions believed to block them from learning how physical objects really move. Whether using RTGs in physics labs helps in the effort to change student misconceptions is currently not well known. How RTGs may be best used to help students to practice scientific methodology and thought, as well as to learn kinematics concepts is likewise not well known. Brassell's (1987) assertion is that a delay of as little as 20 seconds can nullify the effects which using RTGs may have on learning kinematics. As such, investigating the assertion is an excellent vehicle for focusing the research on how these tools may help students to learn physics.

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