Pedagogical Reasoning and Action to Affect Conceptual Change in Student Understanding of Electric Field

Richard B. Cowen
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Abstract

To be written
Chapter 1 - Introduction:

I teach Physics at Pittsford Sutherland High School to 11th and 12th grade students who have elected to take Regents Physics. I decided to make a career change from Healthcare management several years ago after a 25-year career in that field. This is my third year of teaching.

When I started the Graduate program in Math, Science and Technology Education, it was clear to me that I was responsible for knowing the basic content in Physics. I was a Physics major at Penn, graduating with honors, however that was 30 years ago. Since that time I had occasions to apply some of the Physics and Math that I had learned, however, it was very apparent to me that my knowledge base was not very accessible and that many new discoveries had been made. Therefore, I took it upon myself to slowly read a College level text, "Physics" by Cutnell and Johnson (2001). I was particularly impressed with the organization of the book. Each chapter showed the key physical concepts to be learned and how these related to prior concepts. All chapters stressed conceptual understanding, had model problems and realistic problem applications. That approach led to my making a connection with concept mapping. I tried to integrate some of the concept models from individual chapters into one comprehensive one for kinematics and dynamics (first quarter of the course). I was successful in developing an integrated concept map for static and current electricity. This subsequently led me to think about how a student's conception of a topic in Physics might be influenced by teaching. It would be interesting to study this. Subsequently, I discussed this idea with Dr. Lucia Guarino who said that there was a whole field of research called "Pedagogical Content Knowledge (PCK)". The name was so
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understand the definition of PCK and identified a model that is applicable to my research
interest. I was particularly excited by Schulman's belief that case studies are important
for the contribution of knowledge to the field and that teachers should conduct these. A
brief introduction to the several key articles of the literature review (see Chapter 2) is
below.

Professional Literature:

In this seminal article Lee Shulman (1986) raises many provocative questions
regarding how teachers gain content knowledge unique to a topic within a discipline,
decide how to transform it for teaching and select the strategies most useful for teaching
this content in the context of their classroom. He defines "Pedagogical Content
Knowledge" (PCK) as:

"... the particular form of content knowledge that embodies the aspects of
content most germane to its teachability. Within the category of pedagogical
content knowledge I include, for the most regularly taught topics in one’s subject
area, the most useful forms of representation of those ideas, the most powerful
analogies, illustrations, examples, explanations, and demonstrations— in a word, the
ways of representing and formulating the subject that make it comprehensible to
others."
This is the operational definition of PCK that I will use in my research and it provides insights into the need to transform the abstract content of an Electric Field into representations relevant to and understandable by high school students. Shulman also points out the importance and relevance of the use of case studies to inform individual teacher practice and to contribute to the literature.

Shulman (1987) elaborates upon his definition of “Pedagogical Content Knowledge” and provides a “Model of Pedagogical Reasoning And Action.”

“Pedagogical content knowledge, that special amalgam of content and pedagogy that is uniquely the province of teachers, their own special form of professional understanding....It represents the blending of content and pedagogy into an understanding of how particular topics, problems, or issues are organized, represented, and adapted to the diverse interests and abilities of learners, and presented for instruction.”

The model includes: comprehension, transformation (preparation, representation, selection and adaptation to student characteristics), instruction, evaluation, reflection and new comprehensions. This model is adopted to provide a structure for my research study. I have identified transformation (particularly representations) as the critical element of the model that I will focus on.

Petri, J. and Niedderer, H. (1998) describes a case study of the learning process of one student in a 13th grade quantum physics course in Germany. Learning is defined as a change in the stable elements of the cognitive system of the student. The article demonstrates how qualitative research can be conducted to analyze how the conceptual elements of a student change over time. The article supports the constructivist view that
students bring to class a conceptual framework based on prior experiences and learning. Instruction may modify this cognitive structure to a varying extent. It is fascinating in that multiple conceptions often exist simultaneously.

Through an iterative process of discussion, further review of the literature and reflection I arrived at the research focus, topic and four sub-topics to guide this study.

**Focus:** What sources of information can help me to gain a deeper understanding of Electric Field to enable me to create the best representations to build student understanding and knowledge through conceptual change?

How can the Model of Pedagogical Reasoning and Action developed by Shulman (1987) be used to: 1). increase my content knowledge of Electric Fields, 2). help me transform my content knowledge into representations for class presentation, and 3). study conceptual change in two student's understanding of Electric Fields.

**Topic:** Pedagogical Reasoning and Action to Effect Conceptual Change in Student Understanding of Electric Fields.

**Sub-Topics:**

1. Pedagogical content knowledge.
2. Effect of teaching on student concepts and content knowledge.
3. Student concepts and misconceptions with respect to Electric Fields.
4. Methods for evaluating conceptual and content change (including PCK).
Chapter 2 - Review of the Related Literature

Introduction:

Certain topic areas in Physics have traditionally been difficult to teach and difficult for students to understand. The purpose of this literature review is to gain a deeper understanding of pedagogical content knowledge to enable its application in the secondary school physics classroom setting in the teaching of Electric Fields. The typical conceptions and misconceptions that students hold with respect to Electric Fields are reviewed. Lastly methods for assessing conceptual change both in the teacher and in students, including concept maps, are discussed.

Pedagogical Content Knowledge:

In this seminal article Lee Shulman raises many provocative questions regarding how teachers gain content knowledge unique to a topic within a discipline, decide how to transform it for teaching and select the strategies most useful for teaching this content in the context of their classroom. He defines three categories of content knowledge: content knowledge which is the organization of content and principles to incorporate facts; pedagogical content knowledge; and, curricular knowledge which includes what students have been and will be taught in their subject as well as tools for instruction.

He defines “Pedagogical Content Knowledge” (PCK) as:

“... the particular form of content knowledge that embodies the aspects of content most germane to its teachability. Within the category of pedagogical content knowledge I include, the most regularly taught topics in one’s subject area, the most useful forms of representation of those ideas, the most powerful analogies, illustrations, examples, explanations,
and demonstrations-in a word, the ways of representing and formulating the subject that make it comprehensible to others."

Also included in PCK is teacher knowledge of what makes student learning easy or difficult including preconceptions and misconceptions as well as the instructional strategies that will be most useful to change student cognitive structures. The latter are particularly related to experience and to the art of teaching. Shulman also points out the importance and relevance of the use of case studies such as this one to inform individual teacher practice and to contribute to the literature.

Shulman (1987) elaborates upon his definition of Pedagogical Content Knowledge and provides a "Model of Pedagogical Reasoning and Action." (Appendix A)

"Pedagogical content knowledge, that special amalgam of content and pedagogy that is uniquely the province of teachers, their own special form of professional understanding….It represents the blending of content and pedagogy into an understanding of how particular topics, problems, or issues are organized, represented, and adapted to the diverse interests and abilities of learners, and presented for instruction."

The model includes: comprehension, transformation (preparation, representation, selection and adaptation to student characteristics), instruction, evaluation, reflection and new comprehensions. This model will provide a structure for this study of a difficult, abstract concept in Physics. Particular attention will be given to the element of transformation where the investigator will reformulate his knowledge in preparation to teach students. Within the transformation stage the creation of the most powerful representations of content will be stressed based on the hypothesis that these will affect
conceptual understanding. Shulman's model will be used for self-evaluation to identify what the investigator is doing well and what are the opportunities for improvement. In this respect Shulman's model is similar to Continuous Quality Improvement in that it involves academic goal/objective setting, transformation (a process that could be flowcharted), student assessment and reflective teacher feedback.

Veal, William R., MaKinster, James A. build upon Shulman's framework by developing a taxonomy for PCK based on:

"The key to distinguishing the knowledge base of teaching lies at the intersection of content and pedagogy, in the capacity of a teacher to transform the content knowledge he or she possesses into forms that are pedagogically powerful and yet adaptive to the variations in ability and background presented by the students".

This article provides a functional structure for the application of the abstract concept of PCK in this research study. Four levels in the taxonomy are defined of which the latter two will be examined:

1. Pedagogy - General teaching skills that should be developed by all teachers.
2. General PCK - Concepts and strategies for teaching that are specific to the discipline.
3. Domain-specific PCK - Subject matter within a particular discipline.
4. Topic-specific PCK - Teaching styles, methods, and approaches unique to the representation of topics in a discipline.

"A novice teacher tends to rely on unmodified subject matter knowledge, may not have a coherent framework, and makes broad pedagogical decisions without assessing students' prior knowledge, ability levels or learning strategies. They struggle how to transform their knowledge for the specific students they are teaching".

Becoming an effective teacher is not a linear process. All students have experienced teachers who know their content well, but they have not fully learned how to transform that knowledge into meaningful instruction. A secondary science teacher needs to continually develop and to integrate their content knowledge, to develop new topic representations and to learn about student differences while integrating all of these attributes. This article reinforces that the development of PCK is an evolutionary, individual process for each teacher. By focusing on demonstrations, illustrations, student activities, laboratories, and examples specific to the physics-specific topic of an Electric Field, the investigator will utilize and develop improved lesson plans designed toward this aim.

2. Effect of teaching on student concepts

Magnusson, S., Krajcik, J. & Borko, H. (1999) expand on the characteristics of topic-specific PCK. They conceptualize PCK for science teaching as consisting of five components regarding the knowledge and beliefs of a teacher about: 1). teaching orientation as represented by a concept map that guides instructional decisions; 2). science curriculum, goals, objectives and guidelines; 3). student's understanding of
specific science topics; 4) assessment in science; and, 5) instructional strategies for
teaching science that are subject and topic specific.

Of particular importance to this study is their identification of three reasons that students
have difficulty with certain topics:

- Learning is difficult because the concepts are abstract and/or lack connections to
  student experiences.

- Students do not know how translate what they have learned into strategies to find
  solutions.

- Students have misconceptions with respect to scientific concepts.

“It is important to identify topics that require high powered efforts to make
conceptual change. Often teachers hold misconceptions themselves or lacked
crucial knowledge for teaching (p. 107).”

It has been the teacher’s experience during his first three years of teaching that
there are certain topics in physics that are particularly difficult to teach and particularly
difficult for students to grasp. Some of these include projectile motion, forces acting on
an inclined plane, refraction, electric fields and the quantum nature of the atom. In all
cases all three reasons for difficulty are apparent.

The author, McDermott, L.C., (1993) is Professor and Director, Physics
Education Research Group, Washington University and has been involved in this area of
education research for 30 years. The overall premise of her article is that most students
of physics are not ready or able to learn physics in the way that it is currently taught.
Generalizations based on results of her review of the research literature on the teaching of
physics that are germane to this study include:
• "A coherent conceptual framework is not typically an outcome of traditional instruction. Students need to participate in the process of constructing qualitative models that can help them understand relationships and differences among concepts" (p.)

• "Certain conceptual difficulties are not overcome by traditional instruction. Persistent conceptual difficulties must be explicitly addressed by multiple challenges in different contexts" (p.).

• "Connections among concepts, formal representations, and the real world are often lacking after traditional instruction. Students need repeated practice in interpreting physics formalism and relating it to the real world" (p.).

The importance of this article to this study is that the author maintains that the lecture form of teaching is not an effective one for most students. The reliance upon formulae to solve standard quantitative problems does not reflect a deep understanding of physics. Students must be actively involved in learning for significant conceptual change to occur. Questions that require qualitative reasoning and verbal explanation are essential. Students also need time to assimilate new concepts and to apply them to real world situations.


The case study reported by Petri, J. and Niedderer, H., (1998) supports the work of McDermott and of Reif. This article describes the learning process of one student in a 13th grade quantum physics course in Germany. Learning is defined as a change in the stable elements of the cognitive system of the student. The learning pathway is the
resulting sequence of learning states that is used as a basis for analyzing changes from one state to another. The article demonstrates how qualitative research can be conducted to analyze how the conceptual elements of a student change over time and that multiple conceptions may exist simultaneously. A method for data collection and analysis relevant to this research study is described.

3. Student concepts and misconceptions in the selected physics topic to be investigated.


"The purpose of this Resource Letter is to provide an overview of research on learning and teaching in physics. The references have been selected to meet the needs of two groups of physicists engaged in physics education. The first is the growing number whose field of scholarly inquiry is (or might become) physics education research. The second is the much larger community of physics instructors whose primary interest is in using the results from research as a guide for improving instruction".

The authors have selected over 200 articles regarding student general conceptions in physics and conceptual understanding by curriculum topic. This has been an important resource for facilitation of the review of the literature as well as to find articles relevant to Electric Fields.
Furio, C. & Guisasola, J. (1998) report that students have significant difficulties in learning the concept of electric field which is fundamental to electrostatics. Based on their study of over 60 students they conclude that different meanings can coexist for one concept within the individual and that selection of a particular concept for application is based on context.

"the Maxwellian\textsuperscript{1} profile" "is estimated to be conceptually superior and have more power, but the Coulombian\textsuperscript{2} profile is considered to have greater simplicity. Moreover, the construction of the new conceptual profile often asks for the previous acquisition of the old profile (i.e. the introduction of the electric field is not possible without knowing the prerequisites of Coulomb's electric charge and force) and the acknowledgement of its theoretical insufficiencies." (p. 517)

Their results show that students often do not make a clear distinction between field intensity and force. Also, students often do not see that propagation of force is not instantaneous due the limitations of the speed of light and/or the nature of the transmitting medium. Lastly, their article provides a questionnaire with six problems that will be used to ascertain subject knowledge of electric fields.

\textsuperscript{1} Force is a universal property that spreads through space; each point of the force field is associated with intensity and a direction. All charges interact. Force is propagated by the medium. An electric field exists without a test charge to test its presence with electric potential energy as a function of position.

\textsuperscript{2} Electric interaction between separate charges is transmitted instantaneously through space regardless of the medium between them.
References Pending Through Interlibrary Loan

Lillian C. McDermott, L. C., Shafer P. S., and the Physics Education Group at Washington University (2001) have prepared a set of supplemental tutorial and instructional materials designed to aid students in constructing concepts and to facilitate application of these conceptsto real-world settings. The tutorials on Charge and Electric Field (Appendix C) will be used to supplement class and laboratory activities in this study.

4. Methods for evaluating conceptual and content change (including PCK).

Baxter, J.A. & Lederman, N.G. (1999) comment that PCK can not be observed directly. Concept mapping has been used by cognitive researchers to measure knowledge structures as represented by key terms and the relationships among those terms. These can be criticized as restrictive. Gess-Newsome and Lederman (1993) developed a more open-ended technique called pictorial representations based on two questions:

1. “What topics make up your primary teaching content area? If you were to use these topics to diagram your content area, what would it look like?

2. Have you ever thought about your content area in the way you have been asked to do so above?” (p. )

The authors refer to multi-method evaluative approaches developed by Hashweh
and by Smith and Neale. Aspects of all three of these will be incorporated in the research methodology of this study.

Joseph D. Novak of Cornell University has been a leading researcher in the development of cognitive structure and the use of concept mapping as a tool to represent it. In his latest book (1998) he states that:

"Meaningful learning has three requirements:

1. Relevant prior knowledge: That is, the learner must know some information that relates to the new information to be learned in a nontrivial way.

2. Meaningful material: That is, knowledge to be learned must be relevant to other knowledge and must contain significant concepts and propositions.

3. The learner must choose to learn meaningfully. That is, the learner must consciously and deliberately choose to relate new knowledge to knowledge the learner already knows in some nontrivial way." (p. 19)

Novak's definition of a concept is "a perceived regularity in events or objects, or records of events or objects, designated by a label" (p.) He defines principles as relationships between concepts. Conceptual learning occurs during school and subsequently throughout life primarily through concept assimilation or learning through the addition/modification of the concept structure. Due to the importance of assimilation in cognitive development Novak provides a presentation of Ausebel's assimilation learning theory. This is included in this literature review as it is the most widely accepted theory supporting the efficacy of teaching in promoting cognitive change. Ausebel ties meaningful learning to an increase in neural connections. He defines several key ideas to explain meaningful learning:
Subsumption occurs when a major concept absorbs a new one and in turn is somewhat modified. Sometimes concepts are obliterated or forgotten in the formation of new knowledge. "We found that students who took algebra in ninth grade did substantially better with later studies on vectors in physics class, even though much of their specific knowledge from algebra was obliteratively subsumed." (p. 61)

Progressive differentiation of the cognitive structure results from the refinement of concepts.

Integrative reconciliation of concepts involves developing more interrelationships between concepts.

Superordinate learning is a major integration in a domain of knowledge.

The appropriate organization and sequencing of new knowledge to be learned must be planned in such a way to optimize the learner's ability to relate the new knowledge to the concepts and propositions already held.

Concept maps show key ideas and relationships between key ideas. Concept maps:

- Represent the structure of knowledge in a subject.
- Represent knowledge held by the learner (prior and post instruction).
- Help teachers organize material for instruction.
- Help students identify the key concepts.
- Help students eliminate the need for rote learning.
- Allow for sharing of meaning.

When knowledge structures are well-organized, higher order concepts are more inclusive and subsume lower order ones. This is necessary for meaningful learning and problem-solving. The advantages of a robust, well-organized and differentiated cognitive structure include: longer retention, easier subsequent learning, information not subsumed facilitates later learning and ease of application to related problems. The construction and analysis of concept maps is a principal method of assessment of conceptual change in the teacher and in the students to be studied. The above references provide the background and methodology for this.

Summary:

This review of the literature has shown according to the theory of pedagogical content knowledge that teachers should be able to develop representations powerful enough to cause measureable conceptual change in their students. This raises many practical questions including:

- Can conceptual change be designed?
- Are all teachers able do this?
- Are all students able to make conceptual growth?

These are just a few of the questions that are implied from this review of the literature. This study will attempt to make a small contribution to the ongoing study of PCK that is currently in its infancy.
Chapter 3 – Methodology

The research methodology for this study is presented in this chapter in three parts: an overview; a research methodology model; and, a table of specific data sources including how these will be analyzed. The reason for this organization is that it is flexible enough to accommodate the expected changes that will occur in the research methodology during both the data collection and analysis stages of the project.

Overview of research methodology:

1. Select a specific topic in the Regents Physics curriculum that taught to 11th and 12th grade students at Pittsford Sutherland High School in Pittsford, NY. The topic, Electric Fields, was selected from one of the units that are covered during the second semester. The criteria for selection included that the topic was one that:
   - Is recognized in the literature to be a difficult concept for students to learn.
   - The teacher does not believe that he understands it well.
   - Has been difficult for the teacher to teach to students.
   - Students have expressed difficulty in comprehending the topic and test scores have been low.

2. Keep teacher’s field and reflective notes of the sources of information and the learning process that will be used to enhance the teacher’s content knowledge in this topic.

3. Use a multi-method evaluative approach based on the work of Novak, Gess-Newsome and Lederman, Hasweh and Smith and Neale to assess the teacher’s prior content structure regarding PCK and Electrostatics. This will include:
   - Provide a summary of a topic and relate it to a). other ideas in the discipline, b). other areas of knowledge, and c). student’s experience.
- Draw a concept map connecting 20 terms in the teaching area and explain.

- Class instructor interview focused on the teacher's understanding of teaching for conceptual change.

4. Keep teacher's field and reflective notes of sources of information and the learning process that the teacher will use to transform his content knowledge in this topic for presentation to students as well as the specific representations that will be used.

5. The teacher will develop lesson plans to include basic material as well as the specific representations to encourage cognitive change. One of these will be the tutorials developed by McDermott et. al.

6. Use a multi-method evaluative approach based on the work of Novak, Gess-Newsome and Lederman, Hasweh and Smith and Neale to assess the teacher's subsequent content structure regarding PCK and Electrostatics. This will include:

- Provide a modified summary of a topic and relate it to a). other ideas in the discipline, b). other areas of knowledge, and c). student's experience.

- Draw a modified concept map connecting 20 or more terms in the teaching area and explain.

- Sort exam questions into common groups of concepts.

- Class instructor interview focused on teacher's modified understanding of teaching for conceptual change.

- Review by a senior physics teacher that
  
  ✓ Content presentation is accurate
  ✓ Defines terms and monitors use
  ✓ Metaphors and analogies are conceptually accurate
Metaphors and analogies are developmentally appropriate.

7. Compare the lesson plan that has been developed for this study with prior lesson plans that the teacher used as a student teacher and during the prior two years.

8. Select two students with overall equal academic standing for the study based on the following differentiation. One student has taken the Honors Physics course offered in the middle school that is conceptually based. The other student has not taken Physics previously. The rationale behind this is to investigate whether prior exposure to Physics facilitates conceptual development as theorized by Ausubel.

9. Assess the conceptual and content knowledge for both student using prior assessments:
   - Questionnaire developed by Furio, C. & Guisasola, J.
   - Student interview
   - Student narrative
   - Student concept map

10. Assess the conceptual and content change for both student that results from the planned teaching strategies using posterior assessments:
   - Student interview
   - Student narrative
   - Student concept map
Research Model

- Teacher's field and reflective notes
- Teacher's narrative
- Concept maps

Teacher's content knowledge

Transforming teacher knowledge into representations students can understand

- Sources of teacher content knowledge
- Teacher content concept maps

- Sources of teacher PCK
- Teacher representations
- Comparison of lesson plans

Student concept and content change

- Student interviews
- Student narratives
- Student concept maps

- Student topic knowledge
- Student concept maps
Table of specific data sources including how these will be analyzed:

<table>
<thead>
<tr>
<th>Topic/Data Source</th>
<th>Analysis</th>
</tr>
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<tbody>
<tr>
<td><strong>Teacher Content Knowledge</strong></td>
<td></td>
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<tr>
<td>Teacher's field and reflective notes</td>
<td>Sources of teacher learning of new topic content knowledge: literature, experimentation, Internet, other</td>
</tr>
<tr>
<td>Teacher's narrative</td>
<td>A written description of what the teacher knows about the topic before, during and after.</td>
</tr>
<tr>
<td>Concept map</td>
<td>Construct and interpret prior and post concept map based on teacher’s narrative.</td>
</tr>
<tr>
<td><strong>Teacher Transformation of Content Knowledge</strong></td>
<td></td>
</tr>
<tr>
<td>Class instructor interview</td>
<td>Teacher knowledge of teaching for conceptual change.</td>
</tr>
<tr>
<td>Teacher's field and reflective notes</td>
<td>Sources of teacher learning of pedagogic content knowledge: literature, colleagues, other</td>
</tr>
<tr>
<td>Teacher's specific transformational tools</td>
<td>List and determine which are thought to be the most effective based on a review of teacher’s field and reflective notes.</td>
</tr>
<tr>
<td>Analysis of lesson plans</td>
<td>Analyze 4 years of lesson plans to evaluate change over time.</td>
</tr>
<tr>
<td>Update teacher narrative and concept map</td>
<td>Identify modifications.</td>
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<td>Senior physics teacher review</td>
<td>Content accuracy and appropriateness of representations.</td>
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<td><strong>Student Concept Change</strong></td>
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<tr>
<td>Pre-questionnaire</td>
<td>Evaluate student’s prior content knowledge.</td>
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<td>Pre-interview, short spontaneous interviews, post-interview</td>
<td>TBD</td>
</tr>
<tr>
<td>Student narrative</td>
<td>A written description of what the student knows about the topic before and after.</td>
</tr>
<tr>
<td>Concept map</td>
<td>Construct and interpret concept map based on student’s narrative.</td>
</tr>
<tr>
<td>Physics Education Group tutorial</td>
<td>Assess effectiveness of this instrument in facilitating conceptual change.</td>
</tr>
</tbody>
</table>
References:


Veal, William R., MaKinster, James A. (date) Pedagogical Content Knowledge Taxonomies. (journal), (pages)

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Appendixes:
A. Shulman’s Model
B. Constructing Concept Maps – Novak
C. Electric Fields Tutorial – McDermott
D. RBC Concept Maps
E. RBC Old Lesson Plans
to balance our goals of fostering individual excellence with more general ends involving equality of opportunity and equity among students of different backgrounds and cultures. Although most teaching begins with some sort of text, and the learning of that text can be a worthy end in itself, we should not lose sight of the fact that the text is often a vehicle for achieving other educational purposes. The goals of education transcend the comprehension of particular texts, but may be unachievable without it.

Saying that a teacher must first comprehend both content and purposes, however, does not particularly distinguish a teacher from non-teaching peers. We expect a math major to understand mathematics or a history specialist to comprehend history. But the key to distinguishing the knowledge base of teaching lies at the intersection of content and pedagogy, in the capacity of a teacher to transform the content knowledge he or she possesses into forms that are pedagogically powerful and yet adaptive to the variations in ability and background presented by the students. We now turn to a discussion of transformation and its components.
Appendix I: How To Build a Concept Map

1. Identify a focus question that addresses the problem, issues, or knowledge domain you wish to map. Guided by this question, identify 10 to 20 concepts that are pertinent to the question and list these. Some people find it helpful to write the concept labels on separate cards or Post-its™ so that they can be moved around. If you work with computer software for mapping, produce a list of concepts on your computer. Concept labels should be a single word, or at most two or three words.

2. Rank order the concepts by placing the broadest and most inclusive idea at the top of the map. It is sometimes difficult to identify the broadest, most inclusive concept. It is helpful to reflect on your focus question to help decide the ranking of the concepts. Sometimes this process leads to modification of the focus question or writing a new focus question.

3. Work down the list and add more concepts as needed.

4. Begin to build your map by placing the most inclusive, most general concept(s) at the top. Usually there will be only one, two, or three most general concepts at the top of the map.

5. Next select the two, three, or four subconcepts to place under each general concept. Avoid placing more than three or four concepts under any other concept. If there seem to be six or eight concepts that belong under a major concept or subconcept, it is usually possible to identify some appropriate concept of intermediate inclusiveness, thus creating another level of hierarchy in your map.

6. Connect the concepts by lines. Label the lines with one or a few linking words. The linking words should define the relationship between the two concepts so that it reads as a valid statement or proposition. The connection creates meaning. When you hierarchically link together a large number of related ideas, you can see the structure of meaning for a given subject domain.

7. Rework the structure of your map, which may include adding, subtracting, or changing subordinate concepts. You may need to do this reworking several times, and in fact this process can go on indefinitely as you gain new knowledge or new insights. This is where Post-its™ are helpful, or better still, computer software for creating maps.
8. Look for crosslinks between concepts in different sections of the map and label these lines. Crosslinks can often help to see new, creative relationships in the knowledge domain.
9. Specific examples of concepts can be attached to the concept labels (e.g., golden retriever is a specific example of a dog breed).
10. Concept maps could be made in many different forms for the same set of concepts. There is no one way to draw a concept map. As your understanding of relationships between concepts changes, so will your maps.
I. Electrical interactions

A. Press a piece of sticky tape, about 15-20 cm in length, firmly onto a smooth unpainted surface, for example, a notebook or an unpainted tabletop. (For ease in handling, make "handles" by folding each end of the tape to form portions that are not sticky.) Then peel the tape off the table and hang it from a support (e.g., a wooden dowel or the edge of a table).

Describe the behavior of the tape as you bring objects toward it (e.g., a hand, a pen).

B. Make another piece of tape as described above. Bring the second tape toward the first. Describe your observations.

It is important, as you perform the experiment above, that you keep your hands and other objects away from the tapes. Explain why this precaution is necessary.

How does the distance between the tapes affect the interaction between them?

C. Each member of your group should press a tape onto the table and write a "B" (for bottom) on it. Then press another tape on top of each B tape and label it "T" (for top).

Pull each pair of tapes off the table as a unit. After they are off the table, separate the T and B tapes. Hang one of the T tapes and one of the B tapes from the support at your table.

Describe the interaction between the following pairs of tape when they are brought near one another.

- two T tapes
- two B tapes
- a T and a B tape
D. Obtain an acrylic rod and a piece of wool or fur. Rub the rod with the wool, and then hold the rod near newly made T and B tapes on the wooden dowel.

Compare the interactions of the rod with the tapes to the interactions between the tapes in part C. Describe any similarities or differences.

We say that the rod and tapes are electrically charged when they interact as you have observed.

E. Base your answers to the following questions on the observations you have made thus far.

1. Is it possible that there is only one type of charge? If not, what is the minimum number of different types of charge needed to account for your observations thus far? Explain.

2. By convention, a glass rod is said to be “positively charged” when rubbed with silk. Your instructor will tell you whether your acrylic rod is positively or negatively charged when rubbed with the particular material you are using.

How do two objects that are positively charged interact? Explain how you can tell.

Which tape, T or B, has a positive charge? Explain.

Discuss part I with a tutorial instructor before continuing.

Please remove all tape from the tabletop before continuing.

II. Superposition

Coulomb’s law states that the electric force between two point charges acts along the line connecting the two points. (A point charge is a charged object that is sufficiently small that the charge can be treated as if it were all located at a single point.) The magnitude of the force on either of the charges is proportional to the product of the charges and is inversely proportional to the square of the distance between the charges.
A. Two positive point charges \( +q \) and \( +Q \) (with \( |Q| > |q| \)) are held in place a distance \( s \) apart.

1. Indicate the direction of the electric force exerted on each charge by the other.

2. Is the force on the \( +q \) charge by the \( +Q \) charge greater than, less than, or equal to the force on the \( +Q \) charge by the \( +q \) charge? Explain.

3. By what factor would the magnitude of the electric force on the \( +q \) charge change if the charges were instead separated by a distance \( 2s \)?

B. Two more \( +Q \) charges are held in place the same distance \( s \) away from the \( +q \) charge as shown. Consider the following student dialogue concerning the net force on the \( +q \) charge:

Student 1: "The net electric force on the \( +q \) charge is now three times as large as before, since there are now three positive charges exerting forces on it."

Student 2: "I don't think so. The force from the \( +Q \) charge on the left will cancel the force from the \( +Q \) charge on the right. The net electric force will be the same as in part A."

1. Do you agree with either student? Explain.

2. Indicate the direction of the net electric force on the \( +q \) charge. Explain.

3. What, if anything, can be said about how the magnitude of the net electric force on the \( +q \) charge changes when the two \( +Q \) charges are added? Explain.

C. Rank the four cases below according to the magnitude of the net electric force on the \( +q \) charge. Explain how you determined your ranking.

Check your ranking with a tutorial instructor before continuing.
III. Distributed charge

A. Charge an acrylic rod by rubbing it with wool.

Obtain a small pith ball attached to an insulating thread. Touch the ball to the charged rod and observe the behavior of the ball after it touches the rod.

Is the ball charged after it touches the rod? If so, does the ball have the same sign charge as the rod or the opposite sign charge? Explain how you can tell.

B. Hold the charged rod horizontally. Use a charged pith ball to explore the region around the rod. On the basis of your observations, sketch a vector to represent the net electric force on the ball at each of the points marked by an "x."

Is all of the charge on the rod located at a single point? (e.g., Is all the charge at the tip of the rod? At the middle?) Explain how you can tell.

On the basis of the vectors you have drawn, is it appropriate to consider the charged rod as a point charge? Explain.

C. Imagine that two charged rods are held together as shown and a charged pith ball is placed at point \( P \).

Predict whether the rod farther from point \( P \) would exert an electric force on the pith ball. Explain.

Check your prediction by placing a charged pith ball at point \( P \) near two charged rods and then slowly moving one rod away from the other. Describe your observations and discuss with your partners whether your results from this experiment support your prediction.
D. Five short segments (labeled 1–5) of acrylic rod are arranged as shown. All were rubbed with wool and have the same magnitude charge. A charged pith ball is placed in turn at the locations marked by points A and B.

Indicate the approximate direction of the force on the pith ball at points A and B due to segment 5 alone.

What is the direction of the net force on the pith ball at points A and B? Explain how you determined your answer.

Does segment 2 exert a force on the pith ball when the pith ball is placed at point B? Explain.

E. In case A at right, a point charge $+q$ is a distance $s$ from the center of a small ball with charge $+Q$.

In case B the $+q$ charge is a distance $s$ from the center of an acrylic rod with a total charge $+Q$.

Consider the following student dialogue:

Student 1: "The charged rod and the charged ball have the same charge, $+Q$, and are the same distance from the point charge, $+q$. So the force on $+q$ will be the same in both cases."

Student 2: "No, in case B there are charges spread all over the rod. The charge directly below the point charge will exert the same force on $+q$ as the ball in case A. The rest of the charge on the rod will make the force in case B bigger."

Neither student is correct. Discuss with your partners the errors made by each student. Write a correct description of how the forces compare in the space below. Explain.
IV. A model for electric charge
A. A small ball with zero net charge is positively charged on one side, and equally negatively charged on the other side. The ball is placed near a positive point charge as shown.

Would the ball be attracted toward, repelled from, or unaffected by the positive point charge? Explain.

Is your answer consistent with Coulomb's law? Explain.

B. Hang an uncharged metal or metal-covered ball from an insulating string. Then charge a piece of tape as in section 1 and bring the tape toward the ball.

Describe what you observe.

C. The situation in part A suggests a way to think about the attraction in part B between a charged piece of tape and an uncharged metal ball.

Try to account for the attraction in part B. As part of your answer, draw a sketch of the charge distribution on the tape and ball both before and after they are brought near one another.
I. Area as a vector
A. Hold a small piece of paper (e.g., an index card) flat in front of you. The paper can be thought of as a part of a larger plane surface.

What single line could you use to specify the orientation of the plane of the paper (i.e., so that someone else could hold the paper in the same, or in a parallel, plane)?

B. The area of a flat surface can be represented by a single vector, called the area vector \( \vec{A} \).

What does the direction of the vector represent?

What would you expect the magnitude of the vector to represent?

C. Place a large piece of graph paper flat on the table.

Describe the direction and magnitude of the area vector, \( \vec{A} \), for the entire sheet of paper.

Describe the direction and magnitude of the area vector, \( d\vec{A} \), for each of the individual squares that make up the sheet.

D. Fold the graph paper twice so that it forms a hollow triangular tube.

Can the entire sheet be represented by a single vector with the characteristics you defined above? If not, what is the minimum number of area vectors required?

E. Form the graph paper into a tube as shown.

Can the orientation of each of the individual squares that make up the sheet of graph paper still be represented by \( d\vec{A} \) vectors as in part C above? Explain.

F. What must be true about a surface or a portion of a surface in order to be able to associate a single area vector \( \vec{A} \) with that surface?
II. Electric field

A. In the tutorial Charge, you explored the region around a charged rod with a pith ball that had a charge of the same sign as the rod.

Sketch vectors at each of the marked points to represent the electric force exerted on the ball at that location.

How does the magnitude of the force exerted on the ball at point A compare to the magnitude of the force on the ball at point B?

B. Suppose that the charge, \( q_{\text{test}} \), on the pith ball were halved.

Would the electric force exerted on the ball at each location change? If so, how? If not, explain why not.

Would the ratio \( \frac{F}{q_{\text{test}}} \) change? If so, how? If not, explain why not.

C. The quantity \( \frac{F}{q_{\text{test}}} \) evaluated at any point is called the electric field \( E \) at that point.

How does the magnitude of the electric field at point A compare to the magnitude of the electric field at point B? Explain.

D. Sketch vectors at each of the marked points to represent the electric field \( E \) at that location.

Would the magnitude or the direction of the electric field at point A change if:

- the charge on the rod were increased? Explain.

- the magnitude of the test charge were increased? Explain.

- the sign of the test charge were changed? Explain.
The electric field is typically represented in two ways: by vectors or by electric field lines. In the vector representation, vectors are drawn at various points to indicate the direction and magnitude of the electric field at those points. In the field line representation, straight or curved lines are drawn so that the tangent to each point on the line is along the direction of the electric field at that point. Below, we explore how the field line representation can also reflect the magnitude of the electric field.

E. The diagram at right shows a two-dimensional top view of the electric field lines representing the electric field for a positively charged rod.

You determined previously that the magnitude of the electric field at point A was larger than the field at point B. What feature of the electric field lines reflects this information about the magnitude of the field?

III. Flux

Ask a tutorial instructor for a block of wood with nails through it. The nails represent uniform electric field lines. (The block of wood does not represent anything but serves to hold the nails in place.)

At right is a two-dimensional representation of the same electric field as viewed from the side.

A. Compare the magnitude of the electric field at points P and Q. Explain your reasoning.

Suppose you were given another block of wood with nails representing a weaker uniform electric field than the one above. How would the two blocks differ? Explain.

B. Obtain a wire loop. The loop represents the boundary of an imaginary flat surface of area A. (In order to allow the nails that represent the field to pass through the surface, you have only been given the boundary of the surface.)

Draw a diagram to show the relative orientation of the loop and the electric field so that the number of field lines that pass through the surface of the loop is:

- the maximum possible.
- the minimum possible.
Electric field and flux

For a given surface, the electric flux, \( \Phi_E \), is proportional to the number of field lines through the surface. For a uniform electric field, the maximum electric flux is equal to the product of electric field at the surface and the surface area (i.e., \( EA \)). The electric flux is defined to be positive when the electric field \( \vec{E} \) has a component in the same direction as the area vector \( \vec{A} \) and is negative when the electric field has a component in the direction opposite to the area vector.

C. Sketch vectors \( \vec{A} \) and \( \vec{E} \) such that the electric flux is:

<table>
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<tr>
<th>Positive</th>
<th>Negative</th>
<th>Zero</th>
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D. You will now examine the relationship between the number of field lines through a surface and the angle between \( \vec{A} \) and \( \vec{E} \).

(You will need a protractor to measure angles.)

1. Place the loop over the nails so that the number of field lines through it is a maximum; determine the angle between \( \vec{A} \) and \( \vec{E} \). Record both that angle and the number of field lines that pass through the loop.

2. Rotate the loop until there is one fewer row of nails passing through it. Determine the angle between \( \vec{A} \) and \( \vec{E} \) and record your measurement. Continue in this way until \( \theta = 180^\circ \).

3. On graph paper, plot a graph of \( n \) versus \( \theta \). (Let the number of field lines through the surface be a negative number for angles between 90° and 180°.)

E. When \( \vec{E} \) and \( \vec{A} \) were parallel, we called the quantity \( EA \) the electric flux through the surface. For the parallel case, we found that \( EA \) is proportional to the number of field lines through the surface.

By what trigonometric function of \( \theta \) must you multiply \( EA \) so that the product is proportional to the number of field lines through the area for any orientation of the surface?

Rewrite the quantity described above as a product of just the vectors \( \vec{E} \) and \( \vec{A} \).
Concept Map for Resistance and Electrical Circuits - Mr. Cowen

**Electrical**
- Current \( I = \frac{q}{t} \)
- Power \( P = iV \)
- \( P = V^2/R \)
- \( P = \sqrt{2i} \)
- **Ohm's Law** \( R = \frac{V}{I} \)
- **Series-Parallel**
  - \( R_{eq} = R_1 + R_2 \)
- **Parallel**
  - \( \frac{1}{R_{eq}} = \frac{1}{R_1} \)

**Physical**
- **Length** \( L \)
- **Cross-Sectional Area** \( A \)
- **Resistivity**
  - \( \rho \)
- **Material**
- **Temperature** \( T \)