Teacher Knowledge Standards

MSU and Teachers for a New Era

November, 2004
Teacher Knowledge Standards

Michigan State University Teachers for a New Era

Michigan State University
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Preface

The Teachers for a New Era Project has provided the opportunity to review how we educate prospective teachers at Michigan State University and to tailor our expectations and programs to better meet the needs of students in the twenty-first century. These standards are meant primarily for MSU students preparing for teaching careers, all faculty involved in their disciplinary and pedagogical preparation, K-12 teachers and administrators, and public officials responsible for educational policy. We hope that they will also be informative for parents and guardians who are interested in MSU’s perspective on the preparation of teachers.

Teaching is bifocal work: the effective teacher has one eye fixed firmly on content and the other fixed firmly on the students and those individuals and communities affecting their development. The standards that are presented here, therefore, address what teachers need to know and what they need to be able to do with regard to content and context. They are based in a combination of professional judgment and empirical research and will continue to evolve as the research base changes and expands. We move beyond the perennial debate about the relative importance of important content and pedagogy and posit that these standards intersect in important and shifting ways, according to different situations and different pupils. Content knowledge is enriched by teaching that draws on knowledge of one’s pupils and takes advantage of family and community resources. Collectively, these standards depict the experienced teacher who continues to grow professionally. Pre-service students and novice teachers will meet them to greater or lesser degrees at different stages of their development. Formal and self-assessment will be used in the program to assist students in becoming continuous learners and leaders in their profession.

We acknowledge the diligent work of the MSU Teachers for a New Era team members and faculty across the University who contributed to this important effort.

As the collective work of faculty across the disciplines, the MSU Teacher Knowledge Standards represent both our expectations of, and commitment to, the prospective and beginning student-teachers we educate. With a focus on knowledge, pedagogy, assessment and research, these standards fit well with Michigan State University’s mission of Advancing Knowledge and Transforming Lives.

Joan Ferrini-Mundy, Robert Floden, and Barbara Steidle
Editors
November 2004
Mission and Guiding Principles

Teachers transform lives and build society. They are entrusted with pupils to whom they owe a high standard of care and loyalty. That standard includes a commitment to enable all of their students to develop powerful understandings about the world grounded in subject matter, reflecting what scholars have learned about all aspects of life and the environment on our planet. Teachers need to continue to inquire into their teaching practice and strengthen their own subject matter understanding. They are deeply curious both about the subjects they teach, and about students’ development and thinking. They have knowledge of the most current and useful tools and resources for helping students learn. They are able to engage with the contemporary world as well-informed citizens and ethically responsible professionals. Teachers care about the ethical, intellectual, social and emotional development of their pupils, and find ways to make each child’s intelligence, imagination, and knowledge visible in the classroom, through safe, engaging environments. Teachers examine their practice to advance the knowledge and standing of their profession. In questioning their practice, they develop a sense of their own vision, motivation and capacity for teaching their pupils. These pupils bring a wide range of diversity to the classroom. Teachers understand, honor and build on this diversity to enrich the learning community. Education builds the character, commitments and knowledge necessary for exercising the full range of liberties to meet the economic, environmental, social, cultural, and political challenges of a complex world.

To prepare teachers who can transform lives and build society in these ways requires creating strong partnerships among faculty from across the university as well as faculty and administrators in K-12 schools. Through these collaborations we at Michigan State University integrate academic coursework, study abroad, pedagogical preparation and intensive field experiences, internship and induction in schools. Our practice is continuously informed and disciplined by the evidence emerging from research on teaching and learning. We engage our students in activities that are more like our disciplines as we understand and practice them, leading to more thorough understandings of the disciplines, epistemologies and pedagogies. Central to our method is to involve teachers in confronting dilemmas of teaching: we prepare teachers through a practice-oriented, case- and evidence-based theoretical approach.
Introduction to the Michigan State University
Teacher Knowledge Standards

The Teacher Knowledge Standards are organized into six domains:

1. Disciplinary Knowledge for Teaching
2. Families and Communities as Resources
3. Students as Learners
4. Schools, Policies, and Professional Organizations
5. Classrooms for Learning
6. Teachers as Reflective Learners

In the domain of Disciplinary Knowledge, the standards are presented separately, and in different styles, for each of the four core school subject areas: mathematics; literacy, literature, and language studies; integrated science; and social studies. In each of the other domains, standards include a combination of general, cross-cutting expectations, together with standards that are specific to the subject areas. In all but the disciplinary knowledge domain, the standards have been organized into standards of knowledge and action. These standards are purposely not ordered because we view them as integrated and interdependent benchmarks for the development of teachers.

The Disciplinary Knowledge for teaching standards have been developed independently by the four subject matter teams, so at this stage the formats and structures differ considerably by discipline.

The MSU Teacher Knowledge Standards are available in a print version as well as an on-line version. The on-line version (MSU Teacher Knowledge Standards On-Line, http://www.msu.edu/~yadavama/TNE/index.html) includes links that provide elaboration of...
ideas in these standards, links to examples and course descriptions, and details about the assessments that will be incorporated into the MSU Teacher Education program to gauge students’ growth. We plan to select key standards and develop criteria for what would constitute benchmarks for knowledge and performance for educators at three stages: emergent (upon completion of the baccalaureate degree); novice (at the conclusion of the internship experience) and target (at the end of two years of beginning teaching).

The On-Line version is viewed as an evolving resource that will be enriched and extended as MSU students and faculty work with these standards, introduce new courses and experiences into the program, and construct and implement assessment practices linked to the standards.
Disciplinary Knowledge for Teaching: Overview

Prospective teachers are educated in subject matter disciplines and in teacher education. As part of their education within the subject matter disciplines, we are committed to overarching goals in two areas.

The Nature and Practice of Academic Disciplines

First, teachers should have a sense of the overall structures, components, orientations, symbol systems and languages, modes of reasoning, and techniques of inquiry of the disciplinary areas that they will teach. Often a small subset of facts or procedures is seen as representing the totality of an area, yet it is essential for a teacher to see the specifics in the broader context of the disciplines’ broader scope and meaning. In addition, teachers need to be able to see differences across disciplines, and to make connections across the disciplinary subject areas in ways that will support their students’ learning. Prospective teachers should have the capacity to critically examine and use knowledge from a range of sources and orientations in their disciplinary areas, including: narrative knowledge, analytic knowledge, research-based knowledge, applied knowledge, synthesized and integrated knowledge, and imaginative knowledge. They should have the capacity to conduct scientific, mathematical, social, historical, and artistic inquiry.

Autonomous and Collaborative Learning

Prospective teachers should be equipped to continue their education beyond the limits of their preservice teacher education coursework. They should see themselves as continual learners whose knowledge of academic disciplines, resources, teaching, students, and the contexts of schooling will grow and evolve with experience, through a wide variety of formal and informal learning opportunities. Some of the greatest gifts teachers can impart to students are the joy of learning, curiosity, and appreciation for knowledge. Teachers are enabled in this by being active, lifelong learners who have commitments to knowing, learning, and creating. Preservice teacher education should lay a foundation for teachers to be curious, autonomous, life-long inquirers, open to intellectual exploration. They also need the capacity to be collaborative inquirers, exploring questions and working in groups with different people.
Disciplinary Knowledge for Teaching Literacy, Literature, and Language Studies

English Language Arts is an interdisciplinary liberal art that is cross-cutting and foundational for all teaching, regardless of subject matter. Teachers in all disciplines need an understanding of the nature and acquisition of literacy and language as part of their understanding of the role language and literacy play in all of learning. All teachers must be proficient in reading, writing, oral communication, listening and viewing.

As a discipline of study English Language Arts is more broadly conceived in this document, moving beyond traditional views of reading, writing, language, and literary study, to include the following reconceptualizations that:

♦ provide a balance of skills and holistic experiences to enable students to read authentic texts, write for authentic audiences, develop oral presentations for authentic purposes, critically listen and view multi-media presentations.

♦ involve a set of productive, performative, creative, interpretive, and receptive abilities.

♦ involve the interpretation and production of a wide range of modes and genres for multiple purposes ranging from personal to public, from self-expression and understanding to their uses as instruments of social change.

♦ respond to changes in the nature, forms, and consequences of literacy that come with evolving social and technological environments.

♦ address the nature of the existing literary canon and the need for its continuing expansion, its limitations as taught in K-12 classrooms, and the texts beyond the canon, including digital as well as print, that are deserving of study.

♦ view linguistic and cultural differences as resources rather than as problems to be solved.

♦ foster student agency in their uses of literacy to improve and enrich their lives and the lives of others within institutions such as schools and in other community contexts.

This conception of the discipline includes a particular orientation toward knowledge that is not static, but rather dynamic, situated, recursive, socially constructed, experiential, and politically implicated. Teachers with disciplinary knowledge of literacy, literature, and language studies are responsible for understanding these subject matter areas as they relate to content standards and school curriculum appropriate for K-12 instruction. Teachers must be knowledgeable about theory and research related to literacy, literature and language. They employ their knowledge of literature, composition and rhetoric, language theory, research methods, and emerging areas for making decisions about teaching and learning. Teachers are able to connect knowledge to the diversity of students’ lived experiences. In the K-12 classroom, teachers develop subject-
sensitive instructional and assessment practices that support the learning and achievement of their students.

This standard is organized into the three broad categories. Teachers draw upon the first category, *specialized subject matter knowledge*, to make decisions that inform their pedagogy. The knowledge in the second category, *pedagogical content knowledge*, informs decisions about curriculum, teaching practices, and assessment in K-12 classrooms. Educators also need to situate their decisions in a third area of knowledge, *standards and curriculum*, that includes subject matter as it is represented in content standards in specific school curriculum. *Though this standard is organized into three distinct categories, these categories are highly recursive and interrelated. As teachers draw upon these three knowledge areas, they continually connect theory and practice.*

A. Specialized Subject Matter Knowledge

1. The educator is proficient in the use of and knowledge about oral (speaking and listening) and written language for different purposes and in different social and professional contexts. The educator is proficient in the use of tools of inquiry to expand his/her knowledge and understanding of literacy, literature, and language studies.

2. The educator is knowledgeable about theories of literacy (cognitive, socio-cultural, critical, etc.) and research related to these theories. This knowledge includes the interrelationships between and among theories, including how language and literacy processes are fostered by and function in diverse classrooms. Teachers should also know the limitations of theory – and understand the need to appraise them critically.

   a. Multiple literacies
      i. Forms, contexts, and uses of oral, written, visual, and multi-modal texts
      ii. Social, personal, and political implications of uses of literacy
      iii. Changes in the nature of the forms, contexts, and uses of literacy to include new literacy technologies and technological environments

   b. Language acquisition (from the earliest speech perception processes through the acquisition of mature oral and written language)
      i. Acquiring a first language or languages
      ii. Acquiring language other than English
      iii. Fostering and maintenance of heritage languages as well as acquisition of second and foreign languages.
      iv. Second language learning in institutional contexts
      v. Learning the first language for special populations (e.g., hearing and visually impaired)

   c. Receptive and interpretive processes (from emergent to mature)
      i. Reading processes (from basic letter and sound level practices underlying beginning reading to advanced comprehension and interpretive processes including reader response)
      ii. Listening processes (from discriminating basic speech sounds to making sense of complex oral presentations)
iii. Viewing processes (from basic attentional processes to critical interpretations of complex visual presentations)

d. Productive processes (from emergent to mature)
   i. Writing processes (from basic letter and sound mapping processes to highest order composition processes)
   ii. Speaking processes (from understanding how learners acquire the sound system to how they learn to make compelling oral presentations)
   iii. Design processes (from simple showing and pointing out of objects in the environment to designing and performing of multimedia texts)
   iv. Technology processes (how learners acquire skills and use them in writing, speaking, and designing situations – technology impacts literacy products and outcomes)

3. The educator is knowledgeable about the multiplicity of central concepts, content, skills, and structure of literacy, literature, and language studies. The educator also knows about the controversies and conflicts associated with them. The educator thinks critically about this and builds her/his understanding of the following areas as well as their interrelatedness:

a. Literature
   i. A range of traditional, and non-traditional, and contemporary literature, literature from non-western societies and cultures, ethnic literatures, and literature by and about women; literature about race, class, religion and language, a range of genres and texts, including print and digital.
   ii. The social and historical context of texts and authors, and the cultural frameworks that construct them, with balanced representation of the world’s major cultural regions.
   iii. Literary and critical theories and their use in analyzing and responding to texts.

b. Rhetorical theory and practices in written and oral communication
   i. Theories of composing (e.g., process writing, public speaking) and text structures
   ii. Multiple genres and styles in writing and speaking
   iii. Assess and produce within rhetorical situations: audience, purpose, effect
   iv. Rhetorical theory and traditions – strategies and principles for informing, persuading, arguing, and expressing for a variety of audiences and in different genres
   v. How rhetorical forms and functions (the skills of using language effectively and persuasively) are enacted and distributed in cultures and communities

c. Language theory
   i. Show extensive knowledge of and ability to think critically about how and why language varies and changes in different regions of the world, across different cultural and socioeconomic groups, and across different time periods, and incorporate that ability into classroom instruction and assessment that acknowledge and show consistent respect for language diversity.

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1 Genre has traditionally referred to stable categories of written and oral expression. Educators need to have a repertoire of these categories as well as an understanding of their unstable and emergent nature. See A3e.
ii. Show knowledge of how written and oral texts are formally and functionally different

iii. Demonstrate in-depth and critical knowledge about the evolution of the English language and historical influences on its forms, and how to integrate this knowledge into student learning.

iv. Possess an in-depth knowledge and a critical perspective of the theories and models of English grammars (e.g., traditional, transformational).

v. Teachers must understand the impact of culture on linguistic processes and the associations between power and dialect in a variety of social situations.

vi. Knowledge of standard English as one of many dialects and an awareness that all dialects are structured and that teachers who are respectful of culture come to understand the range of dialects of their students (using many tools of inquiry to investigate specific contexts)

d. Research methods
   i. Strategies to read, understand, and evaluate various types of research (both quantitative and qualitative)
   ii. Knowing what methods are available and the implications of using one vs. another (the full range of quantitative and qualitative options)

e. History, Philosophy, and Sociology of literacy, literature, and language studies
   i. Knowledge of the multiple purposes of English Language Arts education over time
   ii. An understanding of paradigm shifts within English Language Arts education
   iii. Knowledge of the politics of literacy and language instruction and how broader socio-cultural imperatives impact English Language Arts instruction

f. Evolving areas or issues of literacy, literature, and language, presently including, but not limited to:
   i. Digital technologies and visual media
   ii. Textuality
   iii. Canon formation
   iv. How new technologies and media stand to change language and literacy practices
   v. Cultural rhetoric
   vi. Shifting understandings of genre

B. Pedagogical content knowledge

1. The educator understands the opportunities and limitations of pertinent resources and is able to select and develop practices that support the learning of all students, including learners of English as a second language, students with special needs, and students underserved because of race, class, gender, and/or religion. These practices include:

   a. Cultivating culturally and linguistically responsive approaches (instructional models, methods, strategies, materials, design, management, assessment) for teaching the Language Arts
   b. Fostering and maintenance of heritage languages as well as acquisition of second and foreign languages.
c. Organizing participation structures that facilitate classroom conversations and include individualized, peer collaborative, and dialogical approaches.

d. Creating environments -- including technological environments -- that encourage language arts development through extensive reading and writing.

e. Constructing and interpreting available assessments to inform appropriately the planning and implementation of instruction (including ongoing monitoring, informal and formal formative assessment tools, teacher-constructed and standardized summative assessments). This entails:
   i. Assessing specialized knowledge (literature and language)
   ii. Assessing abilities (e.g., reading and responding to print and digital texts, writing for a wide range of audiences, effective use of written and oral English).
   iii. Maintaining appropriate proportion of instruction and assessment, to support, not drive instruction
   iv. Referring students for appropriate diagnostic testing (e.g., specific reading, writing, and language difficulties, special education)
   v. Responsibly preparing students for standardized tests
   vi. Understanding how assessments reflect the dominant culture
   vii. Developing pedagogical processes that address the academic realities of students in all strata of society, including groups that have been historically underserved (rural, socio-economically disadvantaged)

2. The educator attends to developmental level of student with respect to designing and carrying out both daily and long-term planning and instruction, producing developmentally appropriate achievement

   a. Emergent literacy and basic skills – engage students in processes of inquiry and critical reflection informed by a student’s level of social and cognitive development, preferences, as well as the best theories and evidence in the field.
      i. How to teach, encourage, enable and assess development of critical receptive, interpretive processes and design meaningful tasks that foster:
         a. Listening for meaning: distinguishing sounds and perceiving patterns
         b. Viewing for meaning: learning where and how to look
         c. Reading for meaning: concepts of print, word recognition, fluency, comprehension, vocabulary development
      ii. How to teach, encourage, enable and assess development of productive processes and design meaningful tasks that foster:
         a. Writing: basic letter and sound mapping
         b. Speaking: articulating sounds
         c. Designing: using objects and motions to communicate

   b. Higher order skills – ask rich questions that cause inferential thinking and that drawn on students’ insight about their communities and the world, and work with socially important ideas that are informed by a student’s level of social, emotional and cognitive development (including adolescent development), preferences, as well as the best theories in the field
i. How to teach, encourage, enable and assess development of reception and interpretation as critical and metacognitive processes, and design meaningful tasks that foster:
   a. Listening: interpreting complex oral texts
   b. Viewing: interpreting visual compositions
   c. Reading: using advanced comprehension and interpretive processes such as constructing critical meanings of text

ii. How to teach, encourage, enable and assess development of production and interpretation as critical and metacognitive processes, and design meaningful tasks that foster:
   a. Writing: making compelling compositions, employing strategies to accomplish rhetorical purposes that include voice, syntax, genre, purpose, word choice, fluency, and audience; standard grammatical conventions; and understanding the effects of decisions about rhetorical purposes and conventions
   b. Speaking: making compelling oral presentations, employing strategies to accomplish rhetorical purposes that include making decisions about voice, effect, genre, purpose, audience
   c. Designing: making compelling visual and multi-modal texts; understanding and producing the visual aspect of writing, including issues of typography and layouts, synthesizing graphics and texts, and multi-modal presentations of texts

C. Knowledge of how to bring theory and practice together relative to specific school and curricular contexts (the “deliverables”)

1. Educators should have critical understanding of standards documents that includes:
   a. Ability to “read” a departmental curricular guide and its placement within a trajectory across grade levels
   b. An understanding of what is state and district mandated and what is discretionary (put into practice within certain contexts)
   c. Ability to find and access resources for implementing guidelines
   d. Knowledge of how to enact the guidelines and put theory into classroom practice
   e. Knowledge of instructional design (e.g., lesson planning, unit design, and long-range planning

2. Knowledge of texts relevant to specific contexts and how to expand that set of texts, ensuring attention to multicultural texts from both within the U.S. and from other countries. These texts include fiction, nonfiction, creative nonfiction, poetry, drama, digital and media texts, including but not limited to:
   a. Children’s literature, young adult literature, secondary level literature
   b. Essays
   c. Memoirs, biography, autobiography
   d. Films, documentaries
   e. Basal texts
3. Opportunities, strategies and skills, appropriate for grade level, for reading and viewing texts:
   a. Letter, sound, word (recognition and semantic) processes
   b. Morphological processes and forms
   c. Syntactic and pragmatic processes (grammar)
   d. Comprehension
   e. Viewing

4. Opportunities, strategies and skills for writing and designing texts
   a. A variety of registers, styles and grammars appropriate to specific contexts
   b. Morphological processes and forms
   c. Grammar as syntactic and pragmatic processes
   d. Rhetorical skills for inventing, organizing, and crafting effective style
   e. Knowledge of the politics of various approaches to teaching writing conventions

5. Opportunities, strategies and skills for oral and visual communication
   a. Speaking, including issues of delivery and visual presentation
   b. Listening as part of being responsive to audience
   c. A variety of registers, styles and grammars appropriate to specific contexts

6. Specialties specific to teaching assignment
   a. Journalism (yearbook, school paper)
   b. Speech Communications (e.g., forensics, public speaking, debate)
   c. Student publishing
   d. Theater
   e. Media studies

7. Opportunities, strategies, and skills for inquiry and research processes
   a. Self-initiated exploration
   b. Formal research process
   c. Multi-genre research products

8. Opportunities, strategies, and skills for and critical appraisal of technological processes
Disciplinary Knowledge for Teaching Mathematics

We have two overriding goals for the preparation of prospective teachers of mathematics. Our first goal is that prospective teachers should understand that mathematics makes sense. By this we mean that prospective teachers should be able to recognize potential connections among ideas in mathematics, recognize the correctness (or incorrectness) of mathematical arguments, and be able to use mathematics successfully to solve a wide range of problems. They should also be committed and prepared to help their own pupils gain an understanding of mathematics, to apply their understanding to produce and recognize valid mathematical reasoning, and to solve problems both within and outside of mathematics.

Our second goal is that prospective teachers should be autonomous as well as collaborative mathematical learners. No teacher preparation program can provide all that is needed to teach mathematics successfully in K-12 schools. Thus, teacher preparation programs at MSU should equip prospective teachers to continue to learn and to understand mathematics and pedagogy of mathematics through formal and informal learning opportunities beyond their undergraduate course work.

In order to emphasize our first goal – that prospective teachers understand that mathematics makes sense – and to move away from the too common perception of mathematics as a list of formulas, calculations and “facts” that need memorizing, we are organizing the standards to emphasize the categories of mathematical knowledge that are basic to understanding and application. This is not to de-emphasize the importance of knowing specific content items – we view mastery of typically listed areas (numbers, algebra, geometry, etc.) as absolutely essential. However, an integral part of understanding mathematics is the ability to use mathematics successfully. To use mathematics successfully, one must have a thorough knowledge of and facility with fundamental definitions, operations, properties and theorems. In addition, prospective teachers should know the reason for and context in which mathematics arises, and connections and underlying ideas in mathematics. They must also be able to develop and critique mathematical arguments, and to solve problems in many areas.

Mathematics often provides insight into difficult problems and yields concise, well-defined processes with which to analyze those problems effectively. Mathematical pursuits also include the seeking of greater efficiency and elegance in solving existing problems. Nowadays, specific mathematical areas and concepts also result from advances in technology that allows mathematicians to begin to address new problems or to look at old ones in new ways.

In general, a mathematical approach involves defining a problem through conjecturing in an established mathematical area. Conjecturing may be supported by technology, by compelling ideas based on past work, computation, or pattern exploration. The precise explanation of a mathematical solution, regardless of the specific problem, starts with definitions and axioms, and builds from there to basic properties, which are then used to obtain desired results. Further understanding of the mathematical ideas so developed can then result from new theorems proven within the existing system, or from exploration---driven by analysis of the system’s limitations---of its underlying assumptions, which can lead to new axioms, definitions, and theorems.
These aspects of mathematical ways of thinking are interrelated and build upon each other. A new problem gives rise to new definitions that give rise to new operations and properties that give us new theorems and results, and those results themselves may lead to further definitions and results. The process never ends.

Knowledge of mathematics for prospective teachers consists of five aspects that are involved in this mathematical approach: origins, mathematical reasoning, specific knowledge, representations and applications. Below we elaborate on each type of knowledge.

A. Origins

The word *origins* refers to the rationale from which a mathematical concept, procedure or problem arises. This rationale may include the seeking of greater efficiency and elegance in solving existing problems, and it may include historical background on a particular concept or problem. Origins may also be psychological or pedagogical (see “Students as Learners” and “Classrooms for Learning” Standards). Mathematics often originates in concrete problems. The resulting mathematical ideas may evolve further in order to address a broader range of problems perhaps not tied to the original one.

One of the simplest examples prospective teachers should understand is the evolution of number systems. The natural numbers are sufficient for counting but not for measuring length or for solving the simplest linear equations. For these tasks we need to extend the system of natural numbers to include the rational numbers. However, the rational numbers are inadequate for solving problems about area or for solving quadratic equations, which require construction of the real and complex numbers.

B. Mathematical reasoning

*Mathematical reasoning* refers to the accepted techniques used to derive or justify knowledge in a mathematical system. Thus, it includes different forms of mathematical argument (e.g. use of specific examples or counterexamples, proof by induction, or proof by contradiction). Mathematical reasoning also includes aspects of logic, (e.g. the equivalence of an if-then statement and its contrapositive, the role of definitions, conjectures and proofs within mathematics, and consequences of changes in assumptions or definitions). (See Math Links 1.1-1.8)

C. Specific subject matter knowledge

*Specific subject matter knowledge* consists of the key assumptions, definitions, algorithms, and theorems of the specific mathematical field being studied. At the K-12 level the mathematical fields typically include numbers & operations, algebra, geometry & measurement, data analysis & probability. At MSU specific mathematics subject matter for teachers includes numbers & number theory, calculus & analysis, geometry, algebra, and statistics. (See Math Links 1.9-1.16)
D. Representations

One way to understand a mathematical concept more fully is to represent it. Mathematical representations consist of the images used to picture or describe an object or process. Many mathematical objects or processes can be represented in many ways. One of the beauties of beginning to see mathematics as a whole is to see the interplay among various areas of the subject. A particular way of representing a problem or concept may lead to an especially efficient or enlightening result. We are able to use mathematics to make sense of problems by employing appropriate representations. Examples:

- We can use area models to represent multiplication of multi-digit numbers or binomial expressions or to illustrate probabilities.
- We can view the Binomial Theorem as a formal result about raising a polynomial to a power, and employ the laws of algebra to give an inductive proof. Equally well, we can think of the Binomial Theorem as telling us how many subsets there are with a given number of elements, or as a result about probability.
- We can view matrices as rectangular arrays of numbers on which are defined certain algebraic operations, or we can view them as linear transformations. Matrices can represent stochastic processes or differential equations. Viewing linear transformations as matrices can advance further understanding through computational experimentation and visualization enhanced by computer technology.

E. Applications

Applications of mathematics abound. Fundamental mathematics developed to solve a particular problem can often be applied to seemingly unrelated problems.

- Example: Calculus was invented to solve problems involving motion, but now it is useful for many other situations.
- Example: The notion of Fourier series, originally intended to solve problems in mathematical physics, plays a fundamental role in the analysis of signals.

Alternatively, one might use the opposite process of going from a particular problem, context, or data set, to a generalization. This could involve existing mathematics or could require developing new mathematics (which connects to the theme of origins).

- Example: Problems about mixtures or population growth lead to abstractions about rates or proportional reasoning.

Experiences with both types of applications help students learn that mathematics both makes sense and can be used to make sense out of the real world.
| Math Link 1.1: | Examples or counterexamples |
| Math Link 1.2: | Proof by induction |
| Math Link 1.3: | Proof by contradiction |
| Math Link 1.4: | Logic |
| Math Link 1.5: | If-then statement |
| Math Link 1.6: | Contrapositive |
| Math Link 1.7: | Role of definitions, conjectures and proofs |
| Math Link 1.8: | Consequences of changes in assumptions or definitions |
| Math Link 1.9: | Numbers & Operations |
| Math Link 1.10: | Algebra |
| Math Link 1.11: | Geometry & Measurement |
| Math Link 1.12: | Data analysis & probability |
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| Math Link 1.14: | Calculus & analysis |
| Math Link 1.15: | Geometry |
| Math Link 1.16: | Algebra |
| Math Link 1.17: | Statistics |
Disciplinary Knowledge for Teaching the Sciences

A framework is presented for explicating the nature of the science understanding that teachers need, followed by an illustration (See Science Link 1.1) focusing on a single topic: mass gain and loss in plants and animals. The framework is used both to organize standards and to suggest ways of assessing teacher candidates’ achievement of those standards, in and out of school classroom contexts.

We can distinguish between typical science teaching—the generally accepted patterns of practice that prevail in science classes both at the K-12 and undergraduate levels—and excellent science teaching—the patterns of practice followed by the best science teachers. Table 1 below suggests some key contrasts between these two patterns of practice.

Table 1: Contrasts between Typical Science Teaching and Excellent Science Teaching

<table>
<thead>
<tr>
<th>Standard/Problem of Practice</th>
<th>Typical Science Teaching</th>
<th>Excellent Science Teaching</th>
</tr>
</thead>
<tbody>
<tr>
<td>Content: Knowing subject matters and how to teach them</td>
<td>Procedural display or telling the story for some topics</td>
<td>Telling the story, practical, AND model-based reasoning about experientially real examples</td>
</tr>
<tr>
<td>Working with students</td>
<td>Students as recipients of science content</td>
<td>Students as apprentices in scientific sense-making</td>
</tr>
<tr>
<td>Teaching strategies: Lesson sequences</td>
<td>Lessons organized around storylines or available materials</td>
<td>Lessons organized around model-based reasoning: Learning and inquiry cycles</td>
</tr>
<tr>
<td>Professional relationships: learning from others</td>
<td>Reliance on imitating role models</td>
<td>Ability to learn from many different mentors and colleagues</td>
</tr>
<tr>
<td>Learning from experience</td>
<td>Superficial analysis and response to experience</td>
<td>Curiosity and rigor in analyzing and responding to experience</td>
</tr>
</tbody>
</table>

A. Deep understanding of fundamental science

We take our central task to be defining and illustrating what it means to understand the topics on those lists—what Hogan and Fisherkeller would describe as compatible-elaborate understanding. We seek to define what it means to understand any topic well enough to teach it effectively at the high school level. Rather than mastery of advanced technical detail, this requires what we will call a deep understanding of fundamental science. Key characteristics of a deep understanding of fundamental science include the following:

---

1. **Sense-making strategies.** Successful science teachers understand the uses and the limitations of different sense-making strategies and can use them appropriately in their interactions with the material world. These strategies include:

   a. **Procedural display:** Producing correct answers by following memorized procedures. Successful science teachers avoid this strategy in their own reasoning and in their expectations for their students.

   b. **Practical reasoning (craft knowledge):** Achieving practical results by reasoning that is action-oriented, person- and context-bound, tacit, integrated, and based on beliefs. Successful science teachers use this strategy and engage their students in it while recognizing its limitations.

   c. **Narrative reasoning:** Making sense of the world in terms of linked, linear sequences of events. Successful science teachers create clear and engaging narrative explanations of systems and phenomena in the material world while recognizing their limitations.

   d. **Model-based reasoning:** Developing and using explicit models or theories that account for phenomena within a domain of applicability. Successful science teachers engage in model-based reasoning about the topics that they teach, recognizing both its limitations and its fundamental importance in scientific sense-making (See Appendix I).

2. **Distinguishing types of knowledge.** Successful teachers can distinguish among three types of knowledge claims that play essential roles in model-based reasoning:

   a. **Experiences:** Observations created through interactions with the objects, systems, and phenomena of the material world. Scientific data are recorded experiences that meet criteria for accuracy and reproducibility.

   b. **Patterns in experience:** Data displays such as charts and graphs; also verbal or mathematical expressions of patterns in experience such as generalizations and scientific laws.

   c. **Theories and models:** Systematic explanations of patterns in experience or data that apply to all data in a domain and can be tested against new data.

3. **Knowing experiences, patterns, and models.** Successful teachers know and understand a substantial number of experiences, patterns, and models relevant to the topics that they teach.

4. **Understanding and engaging in scientific practices: application and inquiry.** Successful teachers can make connections among experiences, patterns, and models through two fundamental types of scientific practices:
a. *Application:* Using scientific models to describe, explain, and predict experiences in their domains, and to design systems or strategies for controlling objects, systems, and phenomena in the material world.

b. *Inquiry:* Using arguments from evidence to find patterns in experience and create explanatory models.

5. *Scientific habits of mind: curiosity and rigor.* Successful science teachers exhibit curiosity about their environments on local and global scales and rigor in their reasoning about our actions with respect to those environments.

Thus a deep understanding of a scientific idea such as photosynthesis or a topic such as Newton’s Laws includes all of the characteristics above. When we say that science teaching requires a deep understanding of fundamental science, we mean that detailed knowledge of advanced topics and models—those not included in the K-12 curriculum—is less important than a deep understanding of the topics and models that are included in the K-12 curriculum.
Disciplinary Knowledge for Teaching the Social Studies

A. Civic Knowledge, Commitments and Capacities

Educators should have the capacity to:

1. Engage in a critical review of fundamental questions of politics and social ethics including how various forms and theories of government understand the nature of political authority, the relationship of the state and civil society to the individual, and the obligations and responsibilities that citizens owe to one another. This includes questions such as

   a. What is the ethical nature of human beings and how do various perspectives on virtue and human nature influence various political stances?
   b. What is the nature and justification of political authority?
   c. What conditions and capacities must people have to claim and exercise their rights?
   d. What are the obligations and responsibilities that citizens owe to one another?
   e. What are the implications of various relationships between the individual and the state or society?
   f. To what extent can individuals and societies be improved and progress? What is progress?

2. Understand the philosophical concepts of American democracy and explain the meaning of core democratic values expressed in the foundational documents of the United States (e.g., the Declaration of Independence, the Constitution), including the consequences of adopting different definitions of “democracy.” Understand the differences between contemporary US democracy and other forms of government, both democratic and non-democratic, in other countries and/or other periods of history.

3. Be able to describe the principles of constitutional government, including the organization and functions of government at the local, state, and federal levels and to explain the characteristics, distribution, and exercise of governmental powers.

4. Develop a sense of human connection and collective responsibility. Reflect on what it means to be a global citizen, on the intellectual history of “global citizenship,” and on how different cultures and social sectors conceive it.

5. Understand human rights and social justice as every person’s right to nutrition, health, shelter, security, work place justice and more broadly happiness, autonomy and cultural, religious and political freedom, including the rights of children.
6. Develop the capacity to see from another’s point of view, including differences which derive in part from national and international diversity (ethnic, linguistic, religious etc).

7. Develop and enact an action plan as a responsible citizen who makes informed judgments and works to advance the common good. Doing this requires being able to explore and reflect on and study the many dimensions of an issue; gather and evaluate information from a wide range of sources on an issue; identify allies; examine and evaluate a range of potential actions and solutions; and understand the roles of citizens, businesses and local, state, national governments and international organizations in resolving this issue.

B. Historical Knowledge, Commitments and Capacities

   Educators should have the capacity to:

1. Engage in a critical review of fundamental questions of history including:
   a. What are the critical events that have shaped the USA and the world?
   b. What are the sources of historical events and how did they develop?
   c. What are the implications and long-term consequences of events?
   d. In what ways are historical developments contingent and not inevitable or planned?
   e. How are historical events both experienced and understood from a variety of perspectives?
   f. What are the theoretical shifts in historical analysis and how are historical interpretations tentative?
   g. How do personal and local histories relate to nation and global histories?

2. Recognize and integrate social, political, economic, and cultural history as well as the history of science and technology in the context of both American and world histories, both Western and non-Western.

3. Reconstruct the past by comparing interpretations and documents.

4. Analyze the patterns of continuity and change, assess relationship among the historical events and explain causes and effects within the contexts of local, national and world history.

5. Use history as a set of tools for understanding the structures, discourses, institutions, and practices of contemporary moment and broader social situations.

C. Geographic Knowledge and Capacities

   Educators should have the capacity to:
1. Engage in a critical review of fundamental questions of geography including:
   a. What are the characteristics and processes of human movement, adaptation, and settlement and how are they different locally, nationally and in international comparative perspective?
   b. What are the interrelationships within and between physical features, cultural aspects of our world, and functions of human systems in comparative perspective, at the local, national and global levels?

2. Describe the patterns and alterations in the distribution, use, and meaning of resources, economic activities, trade, political activities, and information flow in comparative perspective, and how they are different at the local, national and global level?

3. Assess major global processes, their causes and consequences in the geographical context.

4. Be able to describe, explain, and critically interpret the locations and characteristics of ecosystems, climatic systems, and physical patterns of earth, region, and space through organization and presentation of the information in maps, photographs, charts, and graphs.

D. Economic Knowledge and Capacities

Educators should have the capacity to:

1. Engage in a critical review of fundamental questions of economics including:
   a. How do individuals and systems choose what will be produced, distributed, and consumed, by what methods, using what resources, and for whom? How are inevitable inequalities explained and rationalized?
   b. How do the various economic institutions that comprise economic systems (households, businesses, banks, government agencies, labor unions, and corporations) relate to and interact with each other in comparative perspective, at the local, national and global levels?
   c. What are the characteristics of the domestic and global economic systems (including the role of components like tariffs, quotas, and free trade agreements) and how can the interrelationships between them be understood?

2. Recognize the role of major factors such as supply, demand, prices, incentives, profit, tariffs in economic systems. Differentiate between costs and benefits of private and public means to allocate goods and services.

3. Understand transnational capitalism and the reality of an increasingly integrated world-wide economic system coupled with profound and deepening inequality. Recognize the role of major factors such as debt crisis and relief, preferential trade
policies, global food security, balance of trade and payments, free trade and zones, protectionism, quotas, sanctions, and embargoes, tariff and non tariff barriers and currency exchange rates, and fluctuations.

E. Interdisciplinary Global Knowledge and Capacities

Educators should have the capacity to:

1. Understand the processes and impact of key interdisciplinary global issues such as:
   a. An increasingly integrated world-wide economic system.
   b. Increasing concerns about environmental degradation and sustainability. This includes renewable and nonrenewable resources, air, land, water, and seabed pollution; global warming and cooling; ozone depletion; toxic and nuclear wastes, erosion, deforestation, drought, or desertification, and reductions in species varieties.
   c. The complex and varied effects of innovations in technology, media and communications which compress time and space and intermix cultures.
   d. The increasing aggregation of global media conglomerates.
   e. Human demographics, patterns and processes (including birthrates, death rates, fertility rates, migration) and corresponding changes in the social meanings of national identity, transnational identity and ideas of citizenship.
   f. Rising tensions among cultural diversity, traditional civilizations and cosmopolitan global culture.
   g. The new connections, disconnections and unpredictable power dynamics created.

2. Appreciate different cultures yet acknowledges, probes, and confronts deep and sometimes intractable difference, and considers difficult, tragic and frightening global experiences.

3. Understand globalization as a dynamic process (with differential and sometimes inequitable impact) changing social, linguistic, intellectual, and aesthetic values and relationships (among global and local people and places).

4. Recognize the complexity of culture and questions the supposed fixed realities, boundaries, and understandings of an earlier era (nation states, national cultures, identities, divisions between science/nature, reality/appearance, center/periphery, etc.), and thus ideas of subject matter. Recognize the way different cultural aspects of life (such as language, art, music, and belief systems) vary and intertwine across groups, societies, and nations.

5. Recognize a range of national and global interests (political, cultural, ethnic, ideological, and economic) in such matters as economic interactions, weapons deployment, geopolitical conflict, use of natural resources, and human rights concerns. Examine the relationships between them and explain the conditions and motivations that lead to tensions or cooperation.
Students as Learners

Teachers are entrusted with enabling student learning. To maximize learning for all students, teachers must know theories and research on learning and human development (physical, cognitive, emotional, moral, and social). They must understand their individual students, e.g., strengths, interests, and cultural background. Most importantly they must actively draw on these two kinds of knowledge and gather and reflect on new knowledge about their students to make decisions about teaching and learning. In doing so they must set appropriate and challenging expectations and provide the social and emotional support to facilitate learning.

A. Development: General academic (e.g., basic literacy, numeracy, scientific content and thinking skills, social studies content and thinking skills), social, emotional, moral, civic, and physical

1. Cognition and cognitive development (metacognition, strategies, representations of knowledge -- both general and subject specific)
   a. Understanding of reading and writing development and the relationships between them
   b. Understanding development of number concepts and operations, spatial skills and geometric reasoning, and algebraic thinking, and the relationships between them
   c. Understanding how scientific thinking develops
   d. Understanding how thinking associated with the social studies develops, including, for example, civic awareness

2. Language acquisition and how it relates to learning in all subject areas

3. Developmental characteristics of students with special needs and English language learners

4. Social mediational theories (e.g., Vygotsky), as well as other cultural theories of teaching and learning (including gender, ethnic, economic) and the interrelationships among culture, socio-economic factors, language, and schooling

5. Student background (experiences, skills, knowledge, culture) and implications for teaching and learning, including the interrelationships between in and out of school learning (e.g., forms of sponsorship including various family, community, policy impacts)

6. Theories of motivation, and the relationship among motivation, learning, and achievement

7. Assessment of student thinking and learning (e.g., subject-specific approaches to assessment, making inferences about student learning through assessment, incorporating assessment into instruction)
8. Consequences of assessment alternatives for development (i.e., assessment impacts curriculum and instruction which impact development)

9. Institutional impacts on development (e.g., church, government, schools)

B. Issues of Student Access and Agency

1. Learning Resources (e.g., libraries, challenging and appropriate course and materials, technologies, community programs)

2. Institutional gate keeping and organizational structure impacting students

3. Networks of information and human resources (e.g., knowing who makes decisions, what resources are available to serve students, etc.)

C. Actions:

1. Teacher as researcher/inquirer and informed decision maker
   a. Creates and adapts curriculum that builds on students’ interests, strengths, backgrounds (i.e. linguistic, socio-economic, and cultural)
   b. Seeks ways to encourage all students to participate in the activities of the class, treats student differences as resources in the classroom, and adapts the task or environment as needed to support learning
   c. Monitors and checks for students’ understanding (prior knowledge throughout the lesson) and flexibly adjusts plans in response to students and actions, that is committed to scaffolding student learning
   d. Interprets assessments when making instructional decisions (For Literacy, see PCK in Disciplinary Knowledge for Teaching)
   e. Actively seeks ways to get all students to interact and use available technology and other resources to reach learning goals in and out of school

2. Teacher as caring professional
   a. Demonstrates respect and care (consistent with context) for all students, recognizes particular challenges (e.g., social, emotional, academic, economic, linguistic, cultural) students face, and treats all students as capable of learning
   b. Interacts and communicates clearly with students, making students feel cared for and listened to
   c. Models and supports the best of human qualities, including honesty, respect, fairness, and constructive participation with others in and out of school
   d. Develops and applies, implements appropriate interventions (e.g., academic, social, emotional), balancing individual, classroom, and community needs, to enable all students to succeed in and out of school
   e. Learns about students from parents, other professionals in school (See Families and Communities as Resources)
Classrooms for Learning

Teachers are responsible for creating safe and productive classroom environments. Teachers need to know how to create classroom environments where all students can learn. This involves knowing how to manage and organize classrooms so that they are intellectually productive and also safe -- intellectually, emotionally, and physically. In classroom environments where learning is central, teachers also employ instructional technologies that are appropriate to the subject matters they are teaching and that support the intellectual growth of the students in their classroom.

A. Creating an intellectually, emotionally, and physically safe and productive learning community

1. Knowledge about:
   a. Classroom Communities
      i. Communities of learners and learning community qualities (respect, caring, inclusion, inquiry; Subject Matter Group issues: e.g., Social Studies democratic community)
      ii. How classroom communication strategies and participation structures contribute to student learning
      iii. Authenticity of tasks created in learning communities (Subject Matter Group issues: e.g., Mathematics – this raises where mathematical authority resides)
      iv. How student assessment can affect students’ productive learning
      v. Dynamics created by peer influence and classroom demographics (e.g., race, class, gender, disabilities)
      vi. Issues of inclusion for students with disabilities (e.g., physical, emotional, learning, psychological) and appropriate accommodations
      vii. Awareness of how classroom conditions (e.g., student-teacher ratio, overcrowded classrooms, physical space and conditions) can impact classroom dynamics and student learning
   b. Management
      i. Multiple perspectives on classroom management (e.g., on prevention, intervention, inclusive classroom management strategies, the functions of rules and routines)
      ii. Power relationships in the classroom (e.g., teacher and student, among students) and their effects on classroom dynamics and learning
      iii. Promoting positive classroom communities to prevent the occurrence of disruptive students, physical violence in classrooms, bullying, and sexual harassment, and knowledge of appropriate actions for dealing with them.

2. Actions:
   a. Classroom Communities
i. Builds students’ understanding of connections between learning community qualities and subject matter goals (*See subject specific-examples*)

ii. Creates productive environment for learning, where students develop shared values and expectations regarding their interactions, academic work, and responsibilities

iii. Makes the class an inclusive and equitable community, with diverse cultural approaches to community and interaction

iv. Fosters an ethical and democratic environment in the classroom

v. Builds an environment that supports and respects inquiry, curiosity and risk-taking in intellectual and social contexts

vi. Creates a variety of participation structures to engage in meaningful learning, decision-making, problem solving, and conflict resolution.

vii. Uses formative and summative assessments to enhance productive learning

viii. Assesses dynamics of classroom and adapts classroom practice

b. Management

   i. Establishes and maintains regular routines for classroom activity

   ii. Recognizes, analyzes, and works to improve the fit between classroom management strategies and instructional goals

   iii. Establishes functional, attractive, and motivating physical environment in the classroom

   iv. Teaches students to respect and to take care of the classroom environment and resources

   v. Monitors and adapts the physical environment (on a daily basis) to ensure safety and include all students

   vi. Sensitizes students to the needs of their classmates and shows through modeling and direct instruction how to make appropriate accommodations

B. Using educational technologies and tools appropriately and productively to support student learning

1. **Knowledge about:**
   a. Technologies (hardware and software) that can be used in classrooms and schools
   b. Tools that can be used in teaching (manipulatives, materials, etc.) and their role in helping students learn (*See subject-specific examples*)

2. **Actions:**
   a. Organizes and introduces activities and technologies so that students are prepared for them and can carry them out successfully
   b. Makes choices about use and deployment of technology that are appropriate for inquiry, social interaction, and learning
   c. Provides appropriate access to technologies for all students
   d. Teaches students to respect and to take care of technological materials used in their classroom
C. Using curricular materials and instructional resources to design effective teaching

1. **Knowledge about:**
   a. Curricular approaches and alternatives in the subject areas in which one teaches
   b. Useful instructional resources and approaches (see subject specific examples)
   c. Issues to consider in choosing various curricular sequences and approaches relative to impact on student learning and classroom organization

2. **Actions:**
   a. Organizes and introduces activities and instructional sequences so that students are prepared for them and can learn successfully
   b. Makes choices about use and deployment of curricular materials and other instructional resources that are appropriate for inquiry, social interaction, and learning
Teachers as Reflective Learners

Teaching demands self-awareness, reflection, and continual growth. Teachers must be self-reflective, as persons and professionals, understanding that their development occurs over the course of their careers. They must understand the philosophies and passions that motivate their teaching as well as their positions relative to the community (e.g., how they are culturally situated, how they are politically aligned).

A. Knowledge about:
1. One’s values, morals, beliefs, orientations, commitments, strengths, and weaknesses in relation to accepted standards for teaching
2. How one’s personal philosophy of teaching and learning integrates and articulates one’s own values, morals, and commitments
3. The relationship among one’s own learning style and pedagogical tendencies, and potential consequences for particular students
4. How positioning by social and historical forces affects one’s perceptions of difference and pedagogical decisions
5. One’s own personal life experiences and how they affect perceptions and decisions
6. One’s own positions relative to the cultural commitments of the community being served
7. Processes, capacities, and dispositions for learning as a teacher
8. How to recognize and draw upon available resources to construct a teaching persona
9. How one’s teaching persona affects whether and how students learn
10. Systematic self-assessment and goal setting regarding all aspects of teaching, including balancing professional commitments and personal needs
11. The potential impact of individual teachers as agents of change

B. Actions:
1. Articulates, justifies, acts on and adapts personal philosophy of teaching and learning that is consistent with current learning theory and ethical and legal standards of the profession
2. Integrates theories, concepts and ideas from coursework, program experiences, teaching experience and continued professional development, into one’s work
3. Functions as teacher-researcher within his or her classroom
4. Reflects on positioning and personal experiences to form responsive and sensitive relationships with students that enhance learning
5. Projects an effective teacher persona (i.e., how to be who students need you to be in order for students to learn from you)
6. Habitually reflects on feedback and consequences of choices and decisions made to inform future actions and decision-making
7. Learns to negotiate one’s own identity and commitments in response to the perspectives of various stakeholders
8. Recognizes and changes behaviors that are inconsistent with accepted standards for teaching
9. Uses multiple sources of information to form judgments about one’s teaching efficacy
Schools, Policies, and Professional Organizations

Teachers work as part of multiple professional communities, including schools, education systems, and professional associations. Professional teachers understand and embrace productive use of social and professional networks as sources of support. They are knowledgeable about current education policy and policy-makers and can inform and influence policy formation at various levels; i.e. departmental, school, local, state, national.

A. The school as a context for teaching and learning

1. Knowledge about:
   a. Schools as organizations
      i. The impact of goals and mission of schools on teaching and learning
      ii. Decision-making processes and channels for change
      iii. Local professional norms of appearance, manner, and communication
      iv. The impact of possible structures of schools/organizations of school on teaching and learning
         a. Time (e.g., block scheduling, traditional scheduling, trimesters, quarters, specials, etc.)
         b. Material resources (e.g., textbook selection, textbook distribution, laboratory equipment, libraries, etc.)
         c. Human resources (e.g., counselors, media and technology specialists, special education teachers, aides)
         d. Organizational (e.g., teams, departments, looping, multi-age)

2. Actions:
   a. Participates constructively in the life and the community of the school
   b. Participates strategically and appropriately in the construction of goals, missions, and organizational decisions; sets expectations aligned with the goals of the school
   c. Engages with school colleagues, within and across subject areas, in critical appraisal of classroom and school curriculum and instruction; collaborates with school colleagues to develop and implement
   d. Uses the resources of the school to support student learning
   e. Adapts appearance, manner, and communication appropriate to local professional context (school, professional development, university) and develops appropriate demeanor (responsible, reliable, friendly, energetic, reasonable)

B. The education profession as a context for teaching

1. Knowledge about:
   a. Effects on education of social, political, cultural, historical, economic and organizational trends (e.g., awareness of differences between current and historic practices, awareness of great debates such as school restructuring movements, and developments in the disciplines)
b. Research developments, key journals and other sources of information in the field
c. Professional organizations and the resources available for professional development
d. Professional ethics and ethical issues related to education and to the disciplines
e. Certification standards and teacher evaluation processes

2. Actions:
   a. Integrates knowledge of research, theory, and social forces into the design of goals, curriculum, classroom practice, and organization
   b. Locates and uses evidence drawn from professional resources and experiences to continuously develop knowledge about students, curriculum and pedagogy
   c. Draws upon the support of professional associations, unions, supervisors and faculty peers in carrying out immediate duties (making decisions), systematically inquiring about the present, and planning for the future
   d. Participates in the life of the profession to enrich his or her intellectual development and contribute to new knowledge
   e. Models high ethical standards in professional life and teaching practice and incorporates ethical standards in instruction
   f. Actively participates in evaluation and certification processes and uses findings to improve practice

C. The Policy Arena

1. Knowledge about:
   a. The relationship between policy and practice
   b. Standards and how they impact student learning (e.g., Michigan Curriculum Framework, IRA/NCTE/NCTM standards, Subject Matter Group issues)
   c. Relevant state and federal laws (e.g., IDEA, Title IX, NCLB)
   d. Key state and community policy-makers and processes
   e. How the political climate and pressures affect school curriculum and materials selection (e.g., text selection, Subject Matter Group issues)
   f. The range of school and teacher responses to policy and implications of these responses
   g. Accountability
      i. Options for assessing student learning, from informal classroom-based
      ii. Alternatives to high stakes testing
      iii. Structural and content alternatives for students requiring accommodations for assessment (e.g., English Language Learners)
   h. The people to whom they are actually accountable (students, parents, administrators, state and federal policy makers, etc.)

2. Actions:
   a. Identifies and balances various policy options and demands to maximize student benefit, including communicating to students and their families
b. Works with the school, state, and professional organizations to negotiate policy demands in ways that maximize the benefits to the school, state, and profession
c. Participates actively and sensitively in mandatory assessment/accountability practices
d. Forms accountable goals to enhance students learning and measures their success
e. Develops skill in interpretation of assessment results and uses the results to improve instruction and student learning
f. Evaluates curricular assessments and assistive technological product
g. Recognizes and accommodates, to the extent possible, students with conditions requiring special testing arrangements
Families and Communities as Resources

Students’ learning is influenced by the families and communities in which they live. Teachers understand the rich diversity of each student’s family unit and its relationship with the larger community. Teachers use this diversity as a resource in fostering student learning.

A. Family

1. Knowledge about:
   a. How family units are defined in accordance with social norms and cultural practices
   b. How students’ families function (as the primary ethical and moral socializing agents in their children’s lives) in setting expectations and supporting learning
   c. How home environments (e.g., language, culture, ethnicity, socio-economic status) inform pedagogical practices
   d. The cultural commitments of the students’ families (e.g., traditions, histories, habits)
   e. Potential and actual home/school relationships and their role in student learning
   f. The signs of seriously dysfunctional and abusive family situations that threaten student well-being

2. Actions:
   a. Creates learning environments that recognize diversity in family structures.
   b. Treats parents and guardians with respect
   c. Works with parents and guardians to set expectations and support learning for their child, involving them substantively in their child’s education and continuing ethical development
   d. Assesses home school relationships and helps to influence them in order to improve student learning opportunities
   e. Communicates assessment data clearly and sensitively to parents and guardians.
   f. Serves as an advocate for the child and his/her education
   g. Recognizes and responds to signs of family situations that threaten student well-being

B. Community

1. Knowledge about:
   a. The concept of community as a context for teaching and learning
   b. The importance of the broader school community in setting expectations and supporting learning
   c. Diverse cultures and subgroups with different educational goals
   d. The dynamic nature of communities and cultures
   e. Resources within community that support learning
f. Local history and political issues (such as funding initiatives, tensions in leadership, neighborhood schools)
g. Impact of social push for measurables (grades, test scores, etc.) and how that impacts learning and attitude
h. Impact of Socioeconomics on teaching and learning and relationships between parents and schools
i. Transient students (coming in and out of district)
j. Mobility (activities after school, kids with cars, etc.)
k. Recognizes that communities differ in their interpretations of assessments and have arguably defensible positions about test bias.

2. Actions:
   a. Demonstrates flexibility and sensitivity in learning about the community and guarding against stereotypes
   b. Uses community resources to support student growth and achievement
   c. Makes instructional use of issues from local history, politics, or economics
   d. Communicates and interprets aggregated assessment results clearly and sensitively to community members, in ways that convey the strengths and limitations of these measures
   e. Serves as an advocate for children’s welfare in the community at large
Appendix I

Links
Model-based reasoning plays an essential role in a deep understanding of any scientific topic. It is the essential strategy by which scientific communities (in the words of Niels Bohr) “extend our experience and reduce it to order.” The practices of model-based reasoning—inquiry and application—move back and forth across the border between accepted and verified observations—“facts” that are experientially real to people—and the models we use to make sense of those facts. Figure 1, below, represents this process.

The scientific knowledge developed and used through model-based reasoning is immensely valuable to our society, so valuable that we have made it into a required school subject. Scientists’ science, though, is too detailed and complex for children to learn. Thus school science arises out of a reasonable attempt to simplify and organize scientists’ science.

**Figure 1: A Simplified Model of Model-based Reasoning**

Scientists work with uncertain, contested knowledge, on the cutting edge of their disciplines, so they must develop rigorous, persuasive arguments. Students are like scientists in that they are seeking to expand their knowledge of the material world. Argument and persuasion should play a major role in their learning process.

Table 2 below expands on the first row of Table 1, summarizing the key differences between a school science understanding that is inadequate for effective science teaching and a deep understanding of fundamental science that will support effective teaching performance.
Table 1: Contrasts between Content Understanding for Typical Science Teaching and Excellent Science Teaching

<table>
<thead>
<tr>
<th>Elements of Deep Understanding</th>
<th>Typical Science Teaching</th>
<th>Excellent Science Teaching</th>
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<tbody>
<tr>
<td>Sense-making strategies</td>
<td>Primarily procedural display and narrative/metaphorical reasoning</td>
<td>Flexible use of practical, narrative/metaphorical, and model-based reasoning</td>
</tr>
<tr>
<td>Distinguishing types of knowledge</td>
<td>Little distinction between different kinds of “facts”</td>
<td>Recognition of differences between data/experiences and models/theories</td>
</tr>
<tr>
<td>Knowing experiences, patterns, and models</td>
<td>Narrative understanding of patterns and models; limited direct or vicarious experience</td>
<td>Wide variety of experiences (including those that are experientially real to students), patterns, and models</td>
</tr>
<tr>
<td>Understanding and engaging in scientific practices</td>
<td>Explanations connected by linear “storyline” and illustrated by experiences</td>
<td>Models and theories flexibly connected to experiences through practices of application and inquiry, including ability to choose systems and models appropriate for a problem and recognize their limits</td>
</tr>
<tr>
<td>Scientific habits of mind</td>
<td>Curiosity or rigor, but rarely both at once</td>
<td>Commitment to satisfying curiosity through rigorous model-based reasoning</td>
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</table>

Example: Carbon Cycling

We illustrate this approach to defining scientific understanding by exploring a single topic: carbon cycling in earth systems. This is potentially a very large topic, including, for example, production and use of organic carbon through photosynthesis and cellular respiration, movement of organic carbon through food chains and food webs, production of carbon dioxide through burning of fossil fuels, absorption of carbon dioxide by oceans and weathering of calcium silicate rocks, etc. For the purposes of this illustration, we will pick one small sub-topic from the larger topic: *Mass gain and mass loss in plants and animals*.

Note that in defining the topic this way we have already made a decision. We have defined the topic in a way that connects scientific theory with common experiences of high school and middle school students. This ability to make connections between scientific content and things that are experientially real to students is essential to effective science teaching.

The list of characteristics of a deep understanding of fundamental science and Table 1 above suggest that a deep, fundamental understanding of mass gain and loss in plants and animals has five characteristics:
Flexible use of different sense-making strategies, including practical reasoning, narrative reasoning, and model-based reasoning with respect to mass gain and loss in plants and animals.

An ability to distinguish among different types of knowledge claims, including (a) data or observations that attempt to describe and record our experiences with the material world, (b) data displays, laws, and generalizations that describe patterns in data, and (c) models and theories that we use to explain patterns in experience.

Knowledge of particular experiences, patterns, and models relevant to mass gain and loss in plants and animals.

Ability to connect experiences, patterns, and explanations through the scientific practices of inquiry and application with respect to problems involving mass gain and loss in plants and animals.

Exhibiting the scientific habits of mind: curiosity and rigor, in reasoning about mass gain and loss in plants and animals.

The three middle characteristics go together in practice; they are different aspects of model-based reasoning as described in Table 1. Thus our illustration of what it means to have a deep understanding of fundamental science with respect to mass gain and loss in plants and animals has three sections: sense-making strategies, model-based reasoning, and habits of mind.

1. Sense-making Strategies in Carbon Cycling

A deep understanding of fundamental science involves the ability to avoid procedural display and to reason about mass gain and loss in plants and animals using three other sense-making strategies: practical reasoning, narrative reasoning, and model-based reasoning. Productive ways of reasoning about this topic using each of these strategies is discussed below.

a. Practical reasoning. Practical reasoning with respect to mass gain and loss in plants and animals arises for at least three important classes of practical problems:

i. Personal health. Weight control plays a critical role in personal health. Successful science teachers can take advantage of students’ concerns about weight control and beliefs about the effects of diet and exercise in their teaching.

ii. Gardening and agronomy. Students have many reasons to be concerned about mass gain in plants, possibly including their own experiences in growing plants, as well as the multiple ways in which they are dependent on plant growth in farms, pastures, and forests. Successful science teachers can take advantage of these beliefs and concerns.

iii. Pet care and animal husbandry. Finally, students are often concerned with the care and growth of personal pets. Most students are also dependent on animal growth for significant portions of their diets. Successful teachers can tap into these concerns.
We have defined practical reasoning as achieving practical results by reasoning that is action-oriented, person- and context-bound, tacit, integrated, and based on beliefs. These characteristics are apparent in reasoning about the patterns above. Successful farmers, for example, require a wealth of local knowledge about the conditions on their farms and how those conditions affect plant and animal growth. A model-based scientific understanding of how plants and animals grow is arguably helpful to farmers, but there are undoubtedly examples of successful farmers with little understanding of scientific models and of failed farmers who understand the scientific models but not their local contexts. Similarly, successful personal weight control depends on developing an array of practices, beliefs, and habits that may or may not include scientific reasoning about digestion, food storage, and cellular respiration. It is also worth noting that many people have personal beliefs about these problems that are inconsistent with scientific models and are exploited by unscrupulous operators (such as diet supplements that “help you burn away fat overnight while you sleep”).

These practical problems are more interesting and more important to most students than the Krebs cycle and the electron transport chain. Science teachers can gain credibility by having knowledge and skill in these areas. They can also use these problems as entries into model-based reasoning, helping students to understand the mechanisms by which diet, exercise, and growing conditions affect mass gain and loss and to evaluate their personal beliefs and advertising claims.

b. Narrative reasoning. Practical problems like those described above can be embedded in narrative forms. It may be impractical for science teachers to involve students in raising animals in the classrooms or to involve students in experiments with their own diets and exercise habits. It is always possible, though, to turn those practical problems into stories—cases that students can investigate, discuss, and debate. Similarly, it is possible to explain key characteristics of the scientific models below into narrative forms. The story of the journey of a carbon atom from carbon dioxide through a sequence of plant systems—or through a food chain—can be more meaningful to some students than other ways of explicating the structures and functions of systems involved in plant and animal metabolism.

It is important for successful science teachers to understand both the uses and the limits of narrative reasoning. The ability to develop interesting stories, tell them well, and use them wisely is an important asset to science teachers. At the same time, they must realize that the stories (or the diagrams used to illustrate them) are not themselves “science content” that can be learned by students without connections to other forms of reasoning. In particular, there are critical differences between the linear sequences of narrative reasoning and the non-linear, pattern-finding nature of model-based reasoning that science teachers must understand and act on in their teaching.

c. Model-based reasoning. Finally, successful science teachers need to be able to choose appropriate scientific models for reasoning about different problems involving mass gain
and loss in plants and animals and to use those models successfully. Those models are discussed in detail in the next section.

In keeping with Figure 1 and the definition above, model-based reasoning about mass gain and loss in plants and animals includes:

- A set of models, along with system definitions appropriate for each model.
- Experiences and patterns explained by each model.
- Practices or problems that can be addressed using each model.

2. Knowing Experiences, patterns, and models

Table 2 below suggests an array of models that teachers might use to consider mass gain and loss in plants and animals, with their associated systems, experiences, and patterns, arranged roughly in order of scientific depth. Problems and practices associated with each model are discussed in the next section.

Table 2: Alternate experiences, patterns, and models for mass gain and loss in plants and animals

<table>
<thead>
<tr>
<th>Model name and associated systems</th>
<th>Observations or experiences (examples, phenomena, data)</th>
<th>Patterns (laws, generalizations, graphs, tables, categories)</th>
<th>Explanations (models, theories)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Animal biomass model</td>
<td>Multiple food substances, described in “nutrition label” terms: fats, proteins, calories, etc. Experiences with eating, foods satisfying hunger Programs of weight gain and weight loss: Diet, exercise, etc.</td>
<td>Not all ingested substances lead to “real” weight gain Energy content (calories) roughly predicts how foods will contribute to weight gain and loss Limiting calories and exercise both contribute to weight loss</td>
<td>Biomass of animals consists of substances high in chemical energy Animals grow by converting high-energy substances in food to animal biomass Biomass in food and animal tissues can also be “burned” to provide metabolic energy</td>
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<tr>
<td>Systems: Humans and other animals</td>
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<tr>
<td>2. Matter exchange in plants and animals</td>
<td>Data on conditions and substances needed for plant growth; Von Helmont’s experiment Data on gas exchange in plants and animals Tracing labeled atoms into and out of organisms</td>
<td>Carbon cycling in ecosystems: Plants incorporate carbon from CO₂; animals release carbon from food in CO₂ Mass balance in substances entering and leaving plants and animals</td>
<td>Conservation of mass and of atoms in chemical changes Conservation of energy Reduced carbon and hydrogen in organic compounds is associated with chemical potential energy Plants are producers of organic carbon compounds; animals are consumers</td>
</tr>
<tr>
<td>Systems: Plants, animals, substances in their environments</td>
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</tbody>
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3. Internal circulation of food, gases, metabolic wastes
   Systems: Animal and plant organs and tissues
   Investigations of substances in blood, phloem, xylem
   Investigations of exchange of substances in organs and tissues, at cell membranes
   Animals: in lungs/gills; digestion and circulation of small food molecules through blood, waste disposal
   Plants: CO₂ uptake by leaves in light; O₂-CO₂ exchange by all tissue; movement of water and minerals through xylem, sucrose through phloem
   Photosynthesis and cellular respiration as key processes in creating and using food
   Organization of plant and animal systems to provide cells with essential molecules for growth and metabolism, dispose of wastes

4. Cellular growth and metabolism
   Systems: Plant and animal cells
   Biochemical investigations of cell growth and metabolism, including processes in chloroplasts and mitochondria
   Cell growth: Cells are made of complex molecules but only smaller subunits cross cell membranes
   Creation of glucose in chloroplasts from CO₂ and water
   Exchange of substances between mitochondria and other cell parts
   Cell growth: DNA → protein synthesis → synthesis of other cell molecules from subunits that enter across cell membranes
   Light and dark reactions of photosynthesis
   Cellular respiration: Glycolysis, Krebs cycle, electron transport chain

5. Global carbon cycling
   Systems: Carbon-containing organisms, gases, solutions, rocks

6. Physical chemistry of metabolic processes
   Systems: Compounds and reactions in plant and animal cells

7. Fundamental physical processes
   Systems: Fundamental fields and forces

Note that scientists also have other models that can be used to explain aspects of mass gain and loss in plants and animals. For example, models of homeostatic processes explain how plants and animals regulate their masses; developmental models explain the role of mass gain and loss in growth and reproduction; evolutionary models explain how these processes have contributed to the evolutionary success of species.

Note also the discrepancy between the K-12 and university curricula. The K-12 curriculum relies primarily on Models 1-3 above; the university science curriculum focuses more on Models 4-6.
3. Understanding and engaging in scientific practices: application and inquiry

Each of the models above provides conceptual tools that are useful for particular practices and problems:

- **Model 1: Animal biomass.** This model is very useful for practical reasoning about weight gain and loss in animals. It explains, for example why we do not say that someone has “gained a pound” after drinking a pint of water, even though a pint weighs about a pound. It works as well as any of the other models in the table for planning diets and exercise programs. Its weaknesses lie in its limited scope and its relative lack of connection to other scientific models. For example, although this model is compatible with scientific principles of conservation of mass and energy, it is also compatible with the idea that food used for energy is converted to energy or destroyed.

- **Model 2: Matter exchange in plants and animals.** This model enables people to provide accounts of where the biomass of plants and animals comes from and of what happens when animals lose weight that are consistent with the principles of conservation of mass and energy and that enable tracing individual atoms through the system. It connects weight gain and loss with ecological matter cycling by explaining the key differences between plants as producers and animals as consumers. It thus places plants and animals in a much more inclusive narrative of how the world works.

- **Model 3: Internal circulation in plants and animals.** This model enables people to explain key characteristics of plant and animal anatomy and physiology by locating key processes such as gas exchange, digestion, photosynthesis, growth, circulation, and cellular respiration in particular organs and tissues (or in all cells). It makes it possible to predict what substances will be found in different parts of circulatory systems and explain why. It thus supports a narrative that connects matter exchange of plants and animals with their environment with their internal functioning.

- **Model 4: Cellular growth and metabolism.** This model enables people to explain how cells use key substances that pass through their membranes, including biochemical accounts of photosynthesis, cellular respiration, and the synthesis of organic macromolecules within cells. It thus expands the narrative of previous models to include cell structure, function, and biochemistry.

- **Model 5: Global carbon cycling.** In contrast with the reductionist trend in Models 2-4, this model places plants, animals, and ecological carbon cycling in the larger context of carbon pools and fluxes in earth systems, connecting the organic carbon in plant and animal biomass with other systems and processes, that use carbon, including weathering of calcium silicate rocks, dissolving of carbon dioxide in ocean waters, and precipitation and weathering of limestone. It thus enables people to reason about problems involving local and global carbon balances and the accumulation of carbon dioxide in the atmosphere.
• Model 6: Physical chemistry of metabolic processes. This model goes beyond Model 4 by looking closely at the changes in matter, energy, and entropy associated with biochemical processes, explaining how organisms manage to carry out such endothermic processes as the synthesis of glucose from carbon dioxide and water or the synthesis of ATP from ADP and phosphate.

• Model 7: Fundamental physical processes. This model enables people to connect biochemical processes in plants and animals with fundamental fields and forces of quantum mechanics and with the relativistic understanding that mass and energy are two related and interchangeable properties of matter.

Note that the models, individually and in combination, enable all of the sense-making strategies. Each model enables model-based reasoning and practical problem solving within its domain (the systems, data, and patterns that the model explains). In combination, the models provide a detailed account of mass gain and loss in plants and animals that connects these processes with a wide array of scientific theories and with other systems and processes occurring throughout the world and beyond.

For teachers we suggest that it is especially important to attain a compatible-elaborate understanding of the first three models (and perhaps Model 5). In their work secondary science teachers will need to help their students master these models and deal with a wide array of students’ personal experiences and impressions, misconceptions, and ways of reasoning.

4. Scientific habits of mind: curiosity and rigor

Assessment and Data from Current Teachers and MSU Students
We (and other investigators) have developed a variety of questions and interview tasks that assess the model-based reasoning of secondary science teacher candidates and other MSU science students. Selected data from those questions are presented elsewhere. Here are some broad generalizations from those data.

• When presented with practical problems about mass gain and loss in plants and animals, many students respond with informal, practical reasoning, even in situations where the expectation that they will provide model-based answers is clear.

• Students’ informal reasoning about these problems is generally compatible with Model 1 above. It often is not compatible with Model 2, however. In particular, students often suggest explanations that are inconsistent with conservation of mass (particularly in processes involving gases), and students show little commitment to rigorous accounting for all of the matter involved in these processes.

• Teaching students about Model 4 (i.e., detailed biochemical accounts of photosynthesis and cellular respiration) seems to result in procedural display for many students. They provide incomplete and incoherent narratives of these processes, and they do poorly on problems requiring model-based reasoning using Model 4. Furthermore, studying Model
4 in this way does not seem to improve students reasoning on problems calling for the use of Model 2 or Model 3.

- These characteristics of student reasoning are carried over into their teaching practices, which also show a heavy reliance on procedural display and fragmented narratives. This is true even when alternative practices involve model-based reasoning heavily scaffolded by education coursework.

The implications of these patterns for the teaching of our graduates and their students’ learning are apparent.
Appendix II

Teachers for a New Era Team Membership, 2002-2004
## Teachers for a New Era Team Membership, 2002-2004

<table>
<thead>
<tr>
<th>Group</th>
<th>Leaders/Members</th>
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<tr>
<td>Central Office</td>
<td>Barbara Steidle</td>
<td>Provost’s Office</td>
<td>Project Manager</td>
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**Mathematics**

**Induction**
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**Teachers for Urban Schools**

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<td>John Seita</td>
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**Assessment**

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<tr>
<td>Mark Johnson-Lewis</td>
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Appendix III

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