Characteristics of Highly Effective Science Teaching and Learning in Kentucky's Schools

Introduction

This document is an effort to describe the roles of the teacher and student in an exemplary science instructional environment. The focus of the document is on the "instructional core" at the center of the educational process as described in detail in the *Public Education Leadership Program (PELP)* www.hbs.edu/pelp. Future documents will address the "outer ring" factors that are present in science classrooms in high achieving schools and districts – essential resources for science programs, stakeholder involvement, the learning culture, structures and system components, including sustained high quality professional learning opportunities for teachers who are at the core of the instructional process.

PELP Coherence Framework

Note: Only portions of the following documents are cited in the table below. These documents, based on research, articulate the vision for high quality science instruction and have also served as the basis for additional and more current research. Therefore, they should be considered in their entirety as the underlying basis for all of the topics listed.

- **National Research Council (NRC). (1996). *National Science Education Standards*. Washington, DC: National Academy Press.**

- **National Research Council (NRC). (2000). *Inquiry and the National Science Education Standards*. Washington, DC: National Academy Press**
- **National Research Council (NRC). (2001). *Classroom Assessment and the National Science Standards.* Washington, DC: National Academy Press**

In addition, the following state documents provide the framework and guidance for all science instruction in Kentucky:

- **Program of Studies, Revised 2006**
- **Academic Expectations**
- **Core Content for Assessment, Version 4.1**

Knowledge of Content	Research
The teacher: • A. Demonstrates an understanding of the science content in the grades/courses assigned, and an ability to convey this content to students.	**1A.** NRC (National Research Council). 2007. Subject Matter Knowledge for Teaching. In Richard A. Duschl, Heidi A. Schweingruber, and Andrew W. Shouse (Eds.), *Taking Science to school: Learning and Teaching Science in Grades K-8.* (pp. 304-306). Committee on Science Learning, Kindergarten Through Eighth Grade. Board on Science Education, Center for Education, Division of Behavioral and Social Sciences and Education. Washington, DC: the National Academies Press. **1A**. Abell, Sandra K. 2007. Research on Science Teacher Knowledge. Chapter 36 (pp. 1105 – 1149). In *Handbook of Research on Science Education*, Sandra Abell and Norman Lederman, (Eds.), Mahwah, NJ: Lawrence Erlbaum Associates. **1A.** Chaney, B. 1995. Student outcomes and the professional preparation of eighth grade teachers in science and mathematics. Rockville, MD. WESTAT. **1A.** Lee, Okhee. 2005. Science Education for English Language Learners: Synthesis and Research Agenda. *Review of Educational Research* 75 (4), 491-530. * expert science teacher content knowledge is situated within the instructional context, linked strongly with knowledge of students as well

	as an understanding of how students acquire knowledge…
	1A. Monk, D.H. 1994. Subject matter preparation of secondary mathematics and science teachers and student achievement. *Economics of Education Review*, 12(2) 125-145. *teacher preparation in science does not lead to accurate views of science as a knowledge generating process; instead, preservice training typically promotes views of science as a body of facts…
	1A. National Science Teachers Association (NSTA). 2003. *Standards for Science Teacher Preparation*, Standard 1: Content. (pp. 6-14) Arlington, VA: NSTA.
	1A. National Research Council (NRC). 1996. National science education standards. Chapter 6: Science content standards (pp. 103-207). Washington, DC: National Academy Press.
• B. Keeps abreast of current developments in the sciences	**1B**. National Science Teachers Association (NSTA). 2003. *Standards for Science Teacher Preparation*, Standard 4: Issues. (pp. 19-22). Arlington, VA: NSTA.
• C. Designs standards-based courses/lessons/units using *Kentucky's Program of Studies* Revised 2006, *Academic Expectations*, and *Core Content for Assessment Version 4.1*.	**1C**. National Science Teachers Association (NSTA). 2003. *Standards for Science Teacher Preparation*, Standard 6: Curriculum. (pp. 23-24) Arlington, VA: NSTA.
• D. Demonstrates proficiency in the use of measurement and data collection tools and techniques to gather, manage, analyze, and interpret data; including computer-based measurement devices, modeling tools and instructional supports to enhance student learning opportunities.	**1D**. Abd-El-Khalick, F, and BouJaoude, S. 1997. An exploratory study of the knowledge base for science teaching.. *Journal of Research in Science Teaching*, 34, 673-699. * in technology rich classrooms with well trained teachers, students are reported to have expanded their knowledge and skill in problem solving, teamwork, technical expertise, and creativity.
Uses appropriate tools and techniques to gather, analyze, and interpret data	**1D.** James, R. K., C. E. Lamb, D. Householder, M. Bailey. 2000. *Integrating Science, Mathematics, and Technology in Middle School Technology-Rich Environments: A Study of Implementation and Change*. School Science and Mathematics 100 (1), January 2000. * using technology tools and modeling programs requires intensive and extensive training for effective use
• E. Uses and promotes the understanding of appropriate	**1E**. Edelson, D. C., Gordin, D. N., and Pea, R.D. 1999.. Addressing the

scientific vocabulary	challenges of inquiry-based learning through technology and curriculum design. *Journal of the Learning Sciences*, 8, 391-450. *the language of science differs from everyday language; explicit instruction of the science use of terms in context of their application to science concept development supports student learning
• F. Provides essential supports for students in science who are learning English or have limited English proficiency	**1F**. Amaral, O., L. Garrison, and M. Klentschy. 2002. Helping English language learners increase achievement through inquiry-based science instruction. *Bilingual Research Journal* 26 (2): 213-239. **1F**. Gee, James Paul. 2004. Language in the science classroom: Academic social languages as the heart of school-based literacy. In *Crossing Borders in Literacy and Science Instruction: Perspectives on Theory and Practice*, E. Wendy Saul, (Ed). Arlington, VA: National Science Teachers Association and Newark, DE: International Reading Association. * explicit attention to supporting English language learners develop academic language improves science achievement
• G. Accesses a rich repertoire of instructional practices/strategies and applies them appropriately to the particular needs of his/her students aligned with the cognitive demand of the science content (pedagogical content knowledge).	**1G**. Wise, K.C., & Okey, J.R. 1983. A Meta-analysis of the Effects of Various Science Teaching Strategies on Achievement. *Journal of Research in Science Teaching*, 20(5), 419-435. **1G**. National Science Teachers Association (NSTA). 2003. *Standards for Science Teacher Preparation*, Standard 6: Curriculum. (pp 23-24) Arlington, VA: NSTA Standards for Science Teacher Preparation, NSTA, 2003, pp. 22-24 (Standard 5: General Skills of Teaching) **1G**. Calabrese Barton, Angela. 2007. Chapter 12: Science Learning in Urban Settings. In *Handbook of Research on Science Education*, Sandra K. Abell and Norman G Lederman, (Eds.) Mahwah, NJ: Lawrence Erlbaum Associates. **1G**. Oliver, J. Steve. 2007. Chapter 13: Rural Science Education. In *Handbook of Research on Science Education*, Sandra K. Abell and Norman G Lederman, (Eds.), Mahwah, NJ: Lawrence Erlbaum Associates. *specific instructional practices have demonstrated positive impact on the science learning of students in urban settings or rural settings

The students: • H. Use and seek to expand appropriate scientific vocabulary • I. Connect science ideas in different content strands, (Physical, Life, and Earth/space), and in different content areas • J. Use science ideas in realistic problems	**1H**. Lemke, J.L., 1990. *Talking Science: Language, learning and values*. Norwood, NJ: Abllex *… suggests that teachers work deliberately to provide opportunities for students to practice at "talking science." This goal may be accomplished through a variety of means, such as teaching students how to combine scientific terms in complex sentences, discussing their commonsense theories on science topics, teaching students the genres of science writing, and bridging colloquial and scientific language…,

2. Instructional Rigor and Student Engagement	Research
The teacher: • A. Teaches the complex processes, concepts and principles contained in the *Kentucky Core Content for Science,Version 4.1* and the *Program of Studies, Revised 2006* using differentiated strategies that make them accessible to all students	**2A, 2B**. Wise, K.C., & Okey, J.R. 1983. A Meta-analysis of the Effects of Various Science Teaching Strategies on Achievement. *Journal of Research in Science Teaching*, 20(5), 419-435.
• B. Scaffolds instruction to help students reason and develop problem-solving strategies	**2B**. Brooks, J.G., & Brooks, M.G. 1993. *In search of understanding: The case for constructivists classrooms*. Alexandria, VA: Association for Supervision and Curriculum Development. *… deep understanding is formed when students make connections between prior knowledge and new experiences – meaningful learning occurs when they see relationships among ideas.
• C. Consistently demonstrates proficiency with the use of appropriate tools, technology and techniques to solve problems	**2C, 2G**. James, R. K., C. E. Lamb, D. Householder, M. Bailey. 2000. Integrating Science, Mathematics, and Technology in Middle School Technology-Rich Environments: A Study of Implementation and Change. *School Science and Mathematics* 100 (1), January 2000. *using technology tools and modeling programs requires intensive and extensive training for effective use. **2C**. Songer, Nancy Butler. 2007. Chapter 17: Digital Resources Versus Cognitive Tools: A discussion of learning science with technology. In *Handbook of Research on Science Education*, Sandra K. Abell and Norman G. Lederman, (Eds.) Mahwah, NJ: Lawrence Erlbaum Associates.
• D. Provides opportunities for and encourages students to connect multiple representations of scientific ideas, such as pictures, written explanations, symbolic work, diagrams, manipulative models, etc.	**2D**. Smolkin, Laura B. and C. A. Donovan. 2004. Chapter 10: Improving Science Instruction with Information Books: Understanding Multimodal Presentations. In *Crossing Borders in Literacy and Science Instruction: Perspectives on Theory and Practice*, E. Wendy Saul, (Ed.), Arlington, VA: National Science Teachers Association and Newark, DE: International Reading Association.

• E. Orchestrates Engineers effective classroom discussions, questioning, and learning tasks that promote higher-order thinking skills • F. Challenges students to think deeply about problems and encourages/models a variety of approaches to a solution • G. Integrates a variety of learning resources with classroom instruction to increase learning options for all students; these should include guest presenters, field experiences, and career explorations. Brings a variety of learning resources, including guest presenters into the classroom in order to increase learning options for all students. • H. Structures and facilitates ongoing formal and informal discussions based on a shared understanding of rules of scientific discourse	**2E.** Alvermann, Donna E. 2004. Chapter 12: Multiliteracies and Self-questioning in the service of science learning. In *Crossing Borders in Literacy and Science Instruction: Perspectives on Theory and Practice*, E. Wendy Saul, (Ed.), Arlington, VA: National Science Teachers Association and Newark, DE: International Reading Association. * science teaching involves asking and generating questions and developing in students 'metacognition' to help them examine their own knowledge **2G.** National Research Council (NRC). 1996. *National science education standards*. Teaching Standard A, (pp.30-32). Washington, DC: National Academy Press. * "…teachers plan to meet the particular interests, knowledge, and skills of their students and build on their questions and ideas." **2G**. McGinnis, J. Randy and G. P. Stefanich. 2007. Chapter 11: Special needs and talents in science learning. In *Handbook of Research on Science Education*, Sandra K. Abell and Norman G. Lederman, (Eds.), Mahwah, NJ: Lawrence Erlbaum Associates. **2G**. Fradd, S.H., and O. Lee. Teachers' roles in promoting science inquiry with students from diverse language backgrounds. *Educational Researcher* 28, no. 6 (1999): 14-20, 42. **2H, 2I.** Kelly, Greg J. 2007. Chapter 16: Discourses in Science Classrooms. In *Handbook of Research on Science Education*, Sandra K. Abell and Norman G. Lederman, (Eds) Mahwah, NJ: Lawrence Erlbaum Associates. * the inquiry process is moved forward and sustained through dialogic questioning and reflections (metacognition) **2H, 5K.** Abell, Sandra K., G. Anderson and J. Chezem. 2000. Science as Argument and Explanation: In Inquiring into Concepts of Sound in Third Grade. In *Inquiring into Inquiry Learning and Teaching in Science*. Jim Minstrell and Emily H. van Zee. (Eds.), Washington, DC: American Association for the Advancement of Science, pp. 65-80. **2H**. van Zee, Emily H., M. Iwasyk, A. Kurose, D. Simpson, and J. Wild. 2001. Student and teacher questioning during conversations about science. In *Journal of Research in Science Teaching* 38(2), (pp. 159-

• I. Integrates the application of inquiry skills into learning experiences	190). New York, NY: John Wiley and Sons, Inc. **2H**. Herrenkohl, L. and Guerra, M. 1998. Participant structures, scientific discourse, and student engagement in fourth grade. *Cognitions and Instruction 16(4), 431-473.* **2I.** Bransford, J., Brown, A., & Cocking, R. eds. 2000. *How people learn: Brain, mind, experience, and school.* Washington, DC: National Academy Press. **2I.** Minstrell, J. and E. H. van Zee. 2000. Inquiring into Inquiry Learning and Teaching in Science. Washington, DC: American Association for the Advancement of Science. ** integrating inquiry – multi-chapter book with research summaries and instructional implications of the use of 'inquiry' practices… **2I**. Baker, Linda. 2004. Chapter 13: Reading comprehension and science inquiry: Metacognitive connections. In *Crossing Borders in Literacy and Science Instruction: Perspectives on Theory and Practice,* E. Wendy Saul, (Ed.), Arlington, VA: National Science Teachers Association and Newark, DE: International Reading Association. *students comprehension of science concepts interrelates with reading comprehension and build self-awareness/self-questioning skills (metacognition)
• J. Clarifies and shares with students learning intentions/targets and criteria for success. The students: • K. .Articulate and understand learning intentions/targets and criteria for success • L. Read with understanding a variety of informational science texts (articles in popular press, textbooks, non-fiction books, Internet, etc.)	**2J, 2K.** National Research Council (NRC). (2000). *Inquiry and the National Science Education Standards*. (p. 80) Washington, DC: National Academy Press * (Based on *Black and Wilian* research, 1998:) "Unless students can see the criteria by which they will be judged and examples of successful performance, assessment becomes a game of guessing what's in the teacher's head." **2L.** Rosenshine, B., Meister, C.C., & Chapman, S. 1996. Teaching students to generate questions. A review of the interventional studies. Review of Educational Research, 66(2), 181-221.

• M. Apply and refine inquiry skills by: o a. asking and identifying questions and concepts to guide scientific investigations o b. designing and conducting scientific investigations o c. using appropriate technology and mathematics to enhance investigations/problem solving (science probes, graphing calculators, spreadsheets) o d. formulating and revising explanations and models o e. analyzing alternative explanations and models o f. collaborating with other scientists/students o g. accurately and effectively communicating results and responding appropriately to critical comments o h. generating additional testable questions	**2M**. Bybee, R.W., Taylor, J.A., Gardner, A., van Scotter, P., Powell, J.C., Westbrook, A., Landes, N. 2006 *The BSCS 5E Instructional Model: Origins, Effectiveness, and Applications*. Colorado Springs, CO **2M**. Millar, R., & Driver, R., 1987. Beyond Process. *Studies in Science Education*, 14, 33-62. * "… 'cognitive abilities' go beyond what have been termed "process" skills, such as observation, inference, and experimentation. **2M**. American Association for the Advancement of Science. 1989. *Science for All Americans*. Washington, DC: American Association for the Advancement of Science. *Discusses evidence gathering, questioning, and investigating in science classrooms.

3. Instructional Relevance	Research
The Teacher: • A. Designs lessons that allow students to participate in empowering activities in which they understand that learning is a process and mistakes are a natural part of the learning • B. Links concepts and key ideas to students' prior experiences and understandings, uses multiple representations, examples and explanations • C.. Incorporates student experiences, interests and real-life situations in instruction • D. Possesses an understanding of a variety of technology	**3A**. Appleton, Ken. 2007. Pedagogy for Learning in Science. Elementary Science Teaching. Ch. 18: (pp. 510 – 527). In *Handbook of Research on Science Education*, Sandra Abell and Norman Lederman, (Eds.), Mahwah, NJ: Lawrence Erlbaum Associates. *'conceptual change' teaching describes the practices that lead students from existing conceptions of science concepts to an understanding of accepted science explanations of natural events. **3A**. Abu-Hilal, 2000; -----Hembree, 1988, cited in National Research Council. 2004, (p. 196). *Taking Science to School* *Students who have negative views of their competence and low expectations for success are more anxious in learning contexts and fearful of revealing their ignorance. **3B, 3C**. Lee, Okhee and A. Luykx. 2007. Chapter 7: Science Education and Student Diversity: Race/ Ethnicity, Language, Culture, and Socioeconomic Status. In *Handbook of Research on Science Education*, Sandra Abell and Norman Lederman, (Eds.), Mahwah, NJ: Lawrence Erlbaum Associates. *use of student experiences… **3B, 3C**. Calabrese Barton, Angela. 2007. Chapter 12: Science Learning in Urban Settings. In *Handbook of Research on Science Education*, Sandra K. Abell and Norman G Lederman, (Eds.) Mahwah, NJ: Lawrence Erlbaum Associates. **3B, 3C**. Oliver, J. Steve. 2007. Chapter 13: Rural Science Education. In *Handbook of Research on Science Education*, Sandra K. Abell and Norman G Lederman, (Eds.), Mahwah, NJ: Lawrence Erlbaum Associates. *specific instructional practices have demonstrated positive impact on the science learning of students in urban settings or rural settings **3D, 3E.** Abd-El-Khalick, F, and BouJaoude, S. 1997. An exploratory study of the knowledge base for science teaching.. *Journal of Research*

appropriate to the content area, e.g. computer-assisted instruction, CBLs and probes for data collection, scientific and graphing calculators for middle/high school	*in Science Teaching*, 34, 673-699. * in technology rich classrooms with well trained teachers, students are reported to have expanded their knowledge and skill in problem solving, teamwork, technical expertise, and creativity.
• E. Effectively incorporates technology that prepares students to meet future challenges, as articulated in the **Partnership for 21st Century Skills.**	
• F. Works with other teachers to make connections between and among disciplines to show how science is a part of other major subjects	**3F**. Czerniak, Charlene M. 2007. Chapter 19: Interdisciplinary Science Teaching. In *Handbook of Research on Science Education*, Sandra Abell and Norman Lederman, (Eds.), Mahwah, NJ: Lawrence Erlbaum Associates. * interdisciplinary science teaching – equivocal evidence on the impact of interdisciplinary teaching on student achievement, at least as measured by current tools; teacher collaboration, however, shows positive impacts on school climate, which in turn has a strong impact on student achievement, motivation, engagement **3F**. Lemke, Jay L. (2004). Chapter 2: The Literacies of Science. In *Crossing Borders in Literacy and Science Instruction: Perspectives on Theory and Practice*, E. Wendy Saul, (Ed..), Arlington, VA: National Science Teachers Association and Newark, DE: International Reading Association. *…various 'literacies' are needed to be successful science learners. **3F**. Wallace, Carolyn S., B. Hand and Eun-Mi Yang. 2004. Chapter 19: The science writing heuristic: Using writing as a tool for learning in the laboratory. In *Crossing Borders in Literacy and Science Instruction: Perspectives on Theory and Practice*, E. Wendy Saul, (Ed..), Arlington, VA: National Science Teachers Association and Newark, DE: International Reading Association. *the writing heuristic developed by Brian Hand and colleagues has demonstrated effectiveness in helping science students develop skill in using logical argumentation to understand knowledge generation in science; also demonstrates the positive impact on language development **3F**. McBride and Silverman (1991) summarized literature on integration of science and mathematics dating to the early twentieth century and

	concluded with four primary reasons for integrating the subjects: (p. 528-529, Handbook of Research on Science Education.) *Science and mathematics are closely related systems of thought and are naturally correlated in the physical world. Science can provide students with concrete examples of abstract mathematical ideas that can improve learning of mathematics concepts. **3F**. Berlin, D.F. (1994). The integration of science and mathematics education; Highlights from NSF/SSMA Wingspread Conference Plenary Papers. *School Science and Mathematics*. 94(1), 32-35. *"Math can enable students to achieve a deeper understanding of science concepts by providing ways to quantify and explain science relationships. Science activities illustrating mathematics concepts can provide relevancy and motivation for learning mathematics." **3F**. Rutherford, F. J., A. Ahlgren, *Science for All Americans*, 1990 (pp. 16-18), New York, NY. Oxford University Press * "Science provides mathematics with interesting problems to investigate, and mathematics provides science with powerful tools to use in analyzing them." **3F**. Berger, C.F., (1994) Breaking what barriers between science and mathematics? Six myths from a technological perspective. In D.F. Berlin (Ed.), NSF/SSMA Wingspread conference: A network for integrated science and mathematics teaching and learning (pp. 23-27) *School Science and mathematics association topics for Teachers Series (No. 7).* Bowling Green, OH: School science and Mathematics Association. **3F**. Baker, Linda. 2004. Chapter 13: Reading comprehension and science inquiry: Metacognitive connections. In *Crossing Borders in Literacy and Science Instruction: Perspectives on Theory and Practice*, E. Wendy Saul, (Ed.), Arlington, VA: National Science Teachers Association and Newark, DE: International Reading Association. *students comprehension of science concepts interrelates with reading comprehension and build self-awareness/self-questioning skills (metacognition)

The students: • G. Respond to and *pose* non-trivial questions • H. Use appropriate tools and techniques to gather, analyze, and interpret quantitative and qualitative data • I. Explore scientific issues underlying national and local decisions and express positions (in speech and writing) that are scientifically and technologically informed • J. Design and conduct scientific investigations, and use the results to make real-world applications and generate further questions. • K. Recognize and analyze alternative explanations and predictions • L. Think critically and logically to identify the relationships between evidence and explanations • M. Develop descriptions, explanation, predictions, and models using evidence • N. Pose and evaluate models/arguments based on evidence and apply conclusions from such models/arguments • O. Describe, explain and predict natural phenomena • P. Communicate scientific procedures and explanations using appropriate scientific vocabulary • Q. Exhibit skills, attitudes, and values associated with scientific inquiry • R. Evaluate the quality and accuracy of scientific information on the basis of its source and the methods used to generate it.	**3G-3Q.** Bybee, R.W., Taylor, J.A., Gardner, A., van Scotter, P., Powell, J.C., Westbrook, A., Landes, N. 2006. *The BSCS 5E Instructional Model: Origins, Effectiveness, and Applications.* Colorado Springs, CO

4. Learning Climate	Research
The teacher: • A. Creates learning environments where students are active participants in creating, questioning, sharing, discussing, reasoning and analyzing the processes involved in solving scientific problems/tasks • B. Motivates students to achieve, and nurtures their desire to learn in an environment that promotes empathy, compassion, and a mutual respect both among students and between students and the teacher • Nurtures and motivates student desire to learn and achieve and promotes empathy, compassion, and mutual respect among students and between students and teacher. • C. Encourages students to accept responsibility for their own learning and respects the right of each student to ask questions and to request resources to more fully understand, enhance, or add clarity to the learning	**4A**. Fraser, Barry J. 2007. Chapter 5: Classroom Learning Environments. In *Handbook of Research on Science Education*, (pp. 103-124). Sandra Abell and Norman Lederman, (Eds.), Mahwah, NJ: Lawrence Erlbaum Associates. **4A, 4B**. Lee, Okhee and C.W. Anderson. 1993. Task Engagement and Conceptual Change in Middle School Science Classrooms. *American Educational Research Journal*, 30(3) (pp. 585-610) *Two research questions examined: What patterns of students' task engagement emerge as they work on science classroom tasks, and how are patterns of students' task engagement related to factors involving cognition. **4B**. Koballa, T. R., Jr. and S. M. Glynn. Chapter 4: Attitudinal and Motivational Constructs in Science Learning. (pp 75-102). In *Handbook of Research on Science Education*, Sandra Abell and Norman Lederman, (Eds.), Mahwah, NJ: Lawrence Erlbaum Associates. *attitudes and motivation – this research in general education shows the strong impact of motivational forces and student attitudes on science achievement. **4B**. Alexander, P.A., Kulikowich, J.M., and Jetton, T. L., 1994. The role of subject matter knowledge and interest in the processing of linear and nonlinear texts. *Review of Educational Research*, 64, 201-252. **4A, 4B, 4C.** Herrenkhohl, L. R. ,Palincsar, A.S., De Water, L.S., and Kawasaki, K. (1999). Developing scientific communities in classrooms: A sociocognitive approach. *Journal of the Learning Sciences*, 8(3), 451-493. *Reports specific benefits of assigning students roles, as measured by discourse patterns. "…when students were assigned roles, the discourse patterns in the classroom showed increased negotiation of shared understanding, monitoring of comprehension, challenges to others' perspectives, and coordination of theories and evidence." **4B, 4C**. Pintrich, P.S., Marx, R.W., and Boyle, R.A. 1993. Beyond cold

• D. Provides learning experiences that actively engage all students as individuals and as members of collaborative groups	conceptual change: The role of motivational beliefs and classroom contextual factors in the process of conceptual change. *Review of Educational Research*, 63(2), 167-199. *…results of both experimental and classroom-based studies suggest that students' own goals for science learning, their beliefs about their own ability in science, and the value they assign to science learning are likely to influence their cognitive engagement in science tasks **4C, 4D**. Koballa, T. R., Jr. and S. M. Glynn. 1991. Chapter 4: Attitudinal and Motivational Constructs in Science Learning. (pp 75-102). In *Handbook of Research on Science Education*, Sandra Abell and Norman Lederman, (Eds.), Mahwah, NJ: Lawrence Erlbaum Associates. * …this and other research in general education shows the strong impact of motivational forces and student attitudes on science achievement. An illustration of the roles of content knowledge, scientific argument, and social norms in collaborative problem solving.. Paper presented at the annual meeting of the *American Educational Research Association*, April, Chicago, IL. *…productive argumentation in classrooms is more likely to occur when students are permitted and encouraged to talk and work directly with each other, rather than always having their talk mediated through the teacher.
• E. Displays effective and efficient classroom management (e.g., in facilitating cooperative groups, in use of equipment or hands-on materials) • F. Provides sufficient time in science class for students to engage in hands-on experiences and to make connections with these experiences and scientific principles.	**4E, 4F**. National Research Council (NRC). 1996. National science education standards. Chapter 3: Science teaching standards, Standard D (pp. 43-45). Washington, DC: National Academy Press. **4F**. Bredderman, T. 1983. Effects of activity-based elementary science on student outcomes: A quantitative synthesis. *Review of Educational Research* 53 (4): 499-518. **4F**. *Children learn best when they discover through their own concrete experiences (Berlin, 1989; 1990). (Can't find the exact paper.)
The students: • G. Accept responsibility for their own learning • H. Actively participates (regardless of gender, race, ability, or	**4G, 4J**. Wigfield, A. Schiefele, U. Eccles, J. Roeser, R.W., and Davis-Kean, P. 2006. Development of achievement motivation. In W. Damon and N. Eisenberg (Eds.), *Handbook of child psychology: Social, emotional, and personality development* (6th ed., vol3). New York:

disability) • I. Collaborate/team with other students • J. Exhibit a sense of accomplishment and confidence. • K. Take educational risks in class (to refute, defend, etc.)	Wiley. * "…when children answer the questions, Can I do this task? In the affirmative, they try harder, persist longer, perform better, and are motivated to select more challenging tasks." **4J**. Anderman, E.M., and Young, A. 1994. Motivation and strategy use in science: Individual differences and classroom effects. *Journal of Research in Science Teaching*, 31, 811-831. *In a study of sixth and seventh grade science classrooms, students who reported feeling highly efficacious in science and who had a strong sense of competence in science tended to use deep learning strategies and were more focused on learning.
5. Informative Assessment and Reflection	**Research**
The teacher: • A. Uses multiple methods and systematically gathers data about student understanding and ability (formative and summative assessments) • B. Uses student work/data, observations of instruction teaching, assignments and interactions with colleagues to reflect on and improve teaching practice • C. Revises instructional strategies based upon student achievement data (short term and long term)	**5A**. Classroom Assessment and the National Science Education Standards, 2001, J. Myron Atkin, Paul Black, Janet Coffey, (Eds.), Committee on Classroom Assessment and the National Science Education Standards, Center for Education, National Research Council. **5A**. Wiliam, D. and P. Black, "Meanings and Consequences: A Basis for Distinguishing Formative and Summative Functions of Assessment," *British Educational Research Journal*, vol. 22, 1996, pp. 537-48. **5A**. Heritage, Margaret, (2007) *Formative Assessment in the Classroom*. Assessment and Accountability Comprehensive Center. Council of Chief State School Officers. Webex Presentation. **5A, 5B, 5C**. National Science Teachers Association (NSTA). 2003. *Standards for Science Teacher Preparation*, Standard 8: Assessment. (pp. 26-28) Arlington, VA: NSTA. **5 B, 5C, 5F, 5H, 5J, 5L**. Hart, D. (1994) *Authentic Assessment: A Handbook for Educators.* Menlo Park CA: Addison Wesley Publishing Company *Authentic assessment … "is assessment that mirrors and measures student performance in 'real life' tasks and situations." (p. 60.)

• D. Uncovers students' prior conceptions about the concepts to be addressed and addresses students' misconceptions/incomplete conceptions	**5C**. Black, P. & Wiliam, D. (1998b). Inside the Black Box: Raising Standards Through Classroom Assessment. *Phi Delta Kappan*, 80(2), 139-148. * "Firm evidence shows that formative assessment is an essential component of classroom work and that its development can raise standards of achievement…" **5D**. Appleton, Ken. 2007. Pedagogy for Learning in Science. Elementary Science Teaching. Ch. 18: (pp. 510 – 527). In *Handbook of Research on Science Education*, Sandra Abell and Norman Lederman, (Eds.), Mahwah, NJ: Lawrence Erlbaum Associates. * 'conceptual change' teaching describes the practices that lead students from existing conceptions of science concepts to an understanding of accepted science explanations of natural events.
• E. Co-develops scoring guides/rubrics with students and provides adequate modeling to make clear the expectations for quality performance • F. Guides students to apply rubrics to assess their performance and identify improvement strategies • G. Provides regular and timely feedback to students and parents (focused, descriptive, qualitative) that moves learners forward	**5E, 5F**. Siegal, M.A., Hinds, P., Siciliano, M., Nagle, B. Using rubrics to foster meaningful learning, In *Assessment in Science: Practical experiences and educational research*. 2006. M. McMahon, P. Simmons, R. Sommers. D. DeBeats, and F. Crawley (Eds.) Arlington, Va: NSTA Press **5G**. Bangert-Drowns, R. L., Kulik, C-L. C., Kulik, J. A., & Morgan, M. T. (1991). The instructional effect of feedback in test-like events. *Review of Educational Research*, 61(2), 213 - 238.
• H. Allows student to use feedback to improve their work before a grade is assigned • I. Facilitates students in self- and peer-assessment • J. Provides qualitative and quantitative feedback to students on a regular and timely basis (Seems redundant – G.)	**5H, 5I.** Black, P.; Harrison, C.; Lee, C.; Marshall, B. & Wiliam, D. (2003). *Assessment for learning: putting it into practice*. Ch. 4 (pp.30-57). Buckingham, UK: Open University Press. * "The starting point of this book was the realization that research studies worldwide provide hard evidence that development of formative assessment raises students' test scores." Formative assessment, questioning, and self- and peer-assessment are among the topics addressed

The students: • K. Recognize what proficient work looks like and determine steps necessary for improving their work. • L. Develop and/or use scoring guides periodically to assess their own work or that of their peers • M. Use teacher feedback to improve their work *Both teacher and students reflect on work and make adjustments as learning occurs.*	**5A-M**, Vitale, M.R., and N.R. Romance. 2006. A knowledge-based framework for classroom assessment of student science understanding. In *Assessment in Science: Practical experiences and educational research*, eds. M. McMahon, P. Simmons, R. Sommers. D. DeBeats, and F. Crawley. Arlington, VA: NSTA Press. **5A-M**. Black, Paul J. and J. M. Atkin. (1996) *Changing the Subject: Innovations in Science, Mathematics, and Technology Education*. London: Routledge for the Organization for Economic Co-operation and Development.

Reference Resources

The Partnership for 21st Century Skills: Learning for the 21st Century
http://www.21stcenturyskills.org/index.php?option=com_content&task=view&id=29&Itemid=42

The Science Program Improvement Review (National Science Teachers Association) - Vision and Expectations
http://www.nsta.org/about/initiatives/spir/vision.aspxhttp://www.nsta.org/about/initiatives/spir/

National Science Education Standards (National Research Council, 1996)
http://www.nap.edu/readingroom/books/nses/

"Rigor on Trial" by Tony Wagner (Harvard University)
http://www.gse.harvard.edu/clg/pdfs/rigorontrialedweek.pdf

How Students Learn Science in the Classroom
http://www.nap.edu/catalog/11102.html#toc

Kentucky's Program of Studies, Revised 2006: Science
http://education.ky.gov/KDE/Instructional+Resources/Curriculum+Documents+and+Resources/Program+of+Studies/defaulthtm

National Science Teachers Association: Official Positions
http://www.nsta.org/about/positions.aspx