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.
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.

Kentucky Department of Education 2007


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

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<tr>
<th>Knowledge of Content</th>
<th>Research</th>
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<td>1A. Chaney, B. 1995. Student outcomes and the professional preparation of eighth grade teachers in science and mathematics. Rockville, MD. WESTAT.</td>
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* expert science teacher content knowledge is situated within the instructional context, linked strongly with knowledge of students as well...
• B. Keeps abreast of current developments in the sciences


• 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.

Uses appropriate tools and techniques to gather, analyze, and interpret data

• E. Uses and promotes the understanding of appropriate

as an understanding of how students acquire knowledge…


*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…


* 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.


* using technology tools and modeling programs requires intensive and extensive training for effective use

1E. Edelson, D. C., Gordin, D. N., and Pea, R.D. 1999. *Addressing the
<table>
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<th>Scientific Vocabulary</th>
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<td><strong>F.</strong> Provides essential supports for students in science who are learning English or have limited English proficiency</td>
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<td><strong>G.</strong> 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).</td>
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*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*


*explicit attention to supporting English language learners develop academic language improves science achievement*


Standards for Science Teacher Preparation, NSTA, 2003, pp. 22-24 (Standard 5: General Skills of Teaching)


*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


*… 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

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<th>The teacher:</th>
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*… deep understanding is formed when students make connections between prior knowledge and new experiences – meaningful learning occurs when they see relationships among ideas.* |
*using technology tools and modeling programs requires intensive and extensive training for effective use.* |
• 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


* science teaching involves asking and generating questions and developing in students ‘metacognition’ to help them examine their own knowledge


* “…teachers plan to meet the particular interests, knowledge, and skills of their students and build on their questions and ideas.”


* the inquiry process is moved forward and sustained through dialogic questioning and reflections (metacognition)


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-
<table>
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<tr>
<th>I. Integrates the application of inquiry skills into learning experiences</th>
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<td>J. Clarifies and shares with students learning intentions/targets and criteria for success.</td>
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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.)

References:

- **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.”
• 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


* “… ‘cognitive abilities’ go beyond what have been termed ‘process’ skills, such as observation, inference, and experimentation.

*Discusses evidence gathering, questioning, and investigating in science classrooms.
### 3. Instructional Relevance

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|  • 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 | 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.* |
*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.* |
*use of student experiences…* |
*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* |
appropiate to the content area, e.g. computer-assisted instruction, CBLs and probes for data collection, scientific and graphing calculators for middle/high school

- 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

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* 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.

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<td>McBride and Silverman (1991) summarized literature on integration of science and mathematics dating to the early twentieth century and</td>
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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.


*“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.”


*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.

### 4. Learning Climate

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<td><strong>A.</strong> Creates learning environments where students are active participants in creating, questioning, sharing, discussing, reasoning and analyzing the processes involved in solving scientific problems/tasks</td>
<td><strong>4A.</strong> Fraser, Barry J. 2007. Chapter 5: Classroom Learning Environments. In <em>Handbook of Research on Science Education</em>, (pp. 103-124). Sandra Abell and Norman Lederman, (Eds.), Mahwah, NJ: Lawrence Erlbaum Associates.</td>
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<td><strong>B.</strong> 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</td>
<td><strong>4A, 4B.</strong> Lee, Okhee and C.W. Anderson. 1993. Task Engagement and Conceptual Change in Middle School Science Classrooms. <em>American Educational Research Journal</em>, 30(3) (pp. 585-610) <em>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.</em></td>
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<td><strong>C.</strong> 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</td>
<td><strong>4A, 4B, 4C.</strong> Herrenkohl, L. R. , Palincsar, A.S., De Water, L.S., and Kawasaki, K. (1999). Developing scientific communities in classrooms: A sociocognitive approach. <em>Journal of the Learning Sciences</em>, 8(3), 451-493. <em>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.”</em></td>
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<td><strong>4B, 4C.</strong> Pintrich, P.S., Marx, R.W., and Boyle, R.A. 1993. Beyond cold</td>
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• D. Provides learning experiences that actively engage all students as individuals and as members of collaborative groups

• 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.

The students:

• G. Accept responsibility for their own learning
• H. Actively participates (regardless of gender, race, ability, or 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


*…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.


4F. *Children learn best when they discover through their own concrete experiences (Berlin, 1989; 1990). (Can’t find the exact paper.)

### 5. Informative Assessment and Reflection

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)

#### Research

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.


*Authentic assessment … “is assessment that mirrors and measures student performance in ‘real life’ tasks and situations.” (p. 60.)

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- I. Collaborate/team with other students
- J. Exhibit a sense of accomplishment and confidence.
- K. Take educational risks in class (to refute, defend, etc.)

Disability)
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<td><strong>D.</strong> Uncovers students’ prior conceptions about the concepts to be addressed and addresses students’ misconceptions/incomplete conceptions</td>
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<td><strong>E.</strong> Co-develops scoring guides/rubrics with students and provides adequate modeling to make clear the expectations for quality performance</td>
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<td><strong>F.</strong> Guides students to apply rubrics to assess their performance and identify improvement strategies</td>
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<td><strong>G.</strong> Provides regular and timely feedback to students and parents (focused, descriptive, qualitative) that moves learners forward</td>
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<td><strong>H.</strong> Allows student to use feedback to improve their work before a grade is assigned</td>
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<tr>
<td><strong>I.</strong> Facilitates students in self- and peer-assessment</td>
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<tr>
<td><strong>J.</strong> Provides qualitative and quantitative feedback to students on a regular and timely basis (Seems redundant – G.)</td>
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*“Firm evidence shows that formative assessment is an essential component of classroom work and that its development can raise standards of achievement...”*


*‘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.*


*“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.*

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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/default.htm

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