



## **Chèche Konnen Technical Report 2**

Review of Three Elementary School Science Curricula and their Relationships to  
Two Focal Massachusetts State Standards

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REVIEW OF THREE ELEMENTARY SCHOOL SCIENCE CURRICULA AND  
THEIR RELATIONSHIPS TO TWO FOCAL MASSACHUSETTS STATE STANDARDS

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This curriculum review is intended to present an overview of the classroom experiences that students in Massachusetts (MA) are likely to have in Grades 3-5 with the science content associated with two of the MA standards (Massachusetts Department of Education (MA DOE), 2006). Our interest in this topic arose from an interview study we conducted with Grade 5 students in MA, about their answers to six multiple-choice science test items from the Grade 5 MA Comprehensive Assessment System (MCAS). More information concerning the findings of our interview study can be found Rosebery et al. (Rosebery et al., 2010) and Noble et al. (Noble et al., 2012). Our curriculum review was intended to provide background information about the curricula and specific lessons that students in our interview study were likely to encounter in Grades 3-5.

The Grade 5 Science and Technology/Engineering (STE) MCAS test covers learning standards for Grades 3 to 5 in four content areas: (1) Earth and Space Science; (2) Life Science (Biology); (3) Physical Sciences (Chemistry and Physics); and (4) Technology and Engineering. For our interview study, we selected three multiple-choice test items associated with Life Science Standard 2: “Identify the structures in plants (leaves, roots, flowers, stem, bark, wood) that are responsible for food production, support, water transport, reproduction,

growth and protection.” and three test items associated with Physical Sciences (Chemistry and Physics) Standard 3: “Describe how water can be changed from one state to another by adding or taking away heat.” (MA DOE, 2006). An informal survey of area teachers indicated that the Life Science and Physical Sciences content areas were more consistently taught than the Earth and Space Science and Technology and Engineering content areas.

Our three focal test items related to Life Science Standard 2 are shown in Figures 1, 2, and 3, below.

**9** The picture below shows flowering plants.

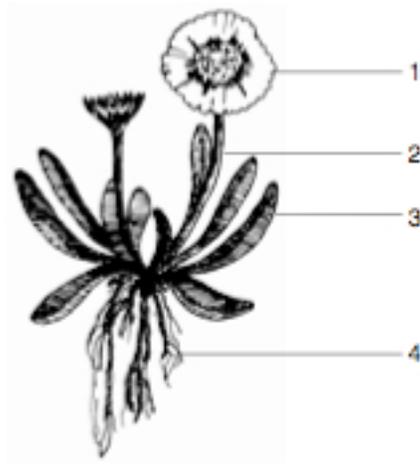


If all the flowers are picked off the plants above, the plants will **not** be able to

- A. grow taller.
- B. produce seeds.
- C. make their own food.
- D. absorb nutrients from the soil.

Figure 1. Flowering Plants (MA DOE, 2003).

- 23** The diagram below shows a plant.



The primary purpose of structure 3 is to

- A. absorb water.
- B. make food.
- C. protect flowers.
- D. produce seeds.

Figure 2. Plant Diagram (MA DOE, 2003).

- 12** The purpose of thorns on a plant is **most likely to**

- A. help the plant to get moisture.
- B. anchor the plant in the ground.
- C. protect the plant from harm.
- D. support the stems and branches.

Figure 3. Purpose of Thorns (MA DOE, 2005).

Our three focal test items related to Physical Sciences Standard 3 are shown in Figures 4, 5, and 6, below.

- 11** Freda always hangs her wet swimsuit outdoors after getting out of the swimming pool. Which of the following is **least likely** to affect the rate at which Freda's swimsuit dries?
- A. the heat of the Sun
  - B. the speed of the wind
  - C. the temperature of the water in the pool
  - D. the amount of water vapor in the air

Figure 4. Freda's Swimsuit test item (MA DOE, 2003).

- 13** If enough heat is taken away from a container of water, what will happen to the water?
- A. It will begin to boil.
  - B. It will become a solid.
  - C. It will turn into a gas.
  - D. It will increase in weight.

Figure 5. Take Away Heat test item (MA DOE, 2004).

- 34** The picture below shows the Sun shining on an open jar with some water in it.



Justin put the jar of water on a picnic table outside in the sunlight. Which of the following pictures shows what Justin would observe after all of the water had turned into a gas?

- A. 
- B. 
- C. 
- D. 

Figure 6. Justin’s Jars test item (MA DOE, 2004).

In order to better understand the experience that Grade 5 students were likely to have with the science of our two focal standards, we reviewed elementary school science curricula related to these two standards and selected three units focused on each standard for in-depth review. The goal of this review was to better understand the experiences of a student who received instruction on the science related to these two standards.

### **Methods**

We selected curricula to review by consulting the National Academy of Science's Resources for Teaching Elementary School Science (1996). According to this document, there are six NSF-funded elementary school science curricula that are comprehensive enough to be used as the sole science curriculum for a school and are currently available. They are the Full Option Science System (FOSS) (Lawrence Hall of Science, 2005a), the Insights curriculum (Education Development Center, 2003a), the Science and Technology for Children (STC) curriculum (National Science Resources Center, 2002), and the Great Explorations in Math and Science (GEMS) curriculum (Lawrence Hall of Science, 2010). Of these four curricula, we selected the three NSF-funded elementary-school curricula that are considered exemplary by the National Science Resources Center and its LASER (Leadership and Assistance for School Reform) center ([http://www.nsrconline.org/curriculum\\_resources/nsf\\_supp\\_curriculum.html](http://www.nsrconline.org/curriculum_resources/nsf_supp_curriculum.html)): FOSS, Insights, and STC. All three curricula are currently in use by schools in MA and across the country, including the two school districts that together provided 89% of the participants in our study.

### **Selecting the Units Related to the Two Standards**

Once we had selected these three curricula, we consulted documents created by the publishers of the curricula correlating these curricula to Massachusetts state standards (Carolina Curriculum, 2010; Delta Education, 2008; Kendall Hunt, 2009) and did a comprehensive search of local libraries for all curriculum materials correlated to the two focal standards. Each curriculum included several different units related in some way to each standard. For each standard, we selected the unit from each curriculum that is typically taught in area districts in Grades 3-5, according to their curriculum plans, and that focuses most directly on the standard. Thus, the units we selected for each standard were those directly targeting the focal standard and including the most significant amount of teaching time on each standard. Science topics and activities related to the two standards are covered in other units as well, but often in a more limited way, or as part of a unit that directly focuses on a different, but related standard. In this way, we selected three curriculum units from each standard for in-depth review.

The units selected from each curriculum for standard are shown in Table 1.

Table 1.

Curriculum units typically used for teaching the content of the two focal standards.

| <b>Curriculum</b> | <b>Unit on Life Science Standard 2</b>                  | <b>Unit on Physical Sciences Standard 3</b>                |
|-------------------|---|--|
| FOSS              | Structures of Life<br>(Lawrence Hall of Science, 2005b) | Water<br>(Lawrence Hall of Science, 2005)                  |
| Insights          | Growing Things<br>(Education Development Center, 2003b) | Changes of State<br>(Educational Development Center, 2003) |
| STC               | Plant Growth and Development<br>(NSRC, 1991)            | Changes<br>(National Science Resources Center, 2002)       |

### Selecting the Content Related to each Standard

Each curriculum unit was reviewed in detail by two researchers with backgrounds in science education. Each researcher marked every page of the unit on which there was mention of science content related to one of the two focal standards. From these notations, one researcher with a background in biology and science education created a complete description of the science activities, background information for teachers, and material presented to students for each unit associated with Life Science Standard 2. A researcher with a background in physics and science education used these notations to create a parallel description for each unit associated with Physical Sciences Standard 3. Summaries of these descriptions are given in Table 2.

Table 2.

Summary of activities related to Life Science Standard 2 and Physical Sciences Standard 3.

| <b>Curriculum</b> | <b>Topics of activities related to Life Science Standard 2</b>                             | <b>Topics of activities related to Physical Sciences Standard 3</b>   |
|-------------------|--|---|
| FOSS              | the origin of seeds, the life cycle of the bean, and growing bean plants using hydroponics | melting, freezing, evaporation (drying), and condensation of water and the role of heat or temperature in all of these          |
| Insights          | examination of the insides of seeds and the growth of roots.                               | melting, freezing, and condensation of water, evaporation (drying) of alcohol, the role of heat or temperature in all of these. |
| STC               | growing and observing Brassica plants from seed to seed                                    | melting, freezing, evaporation, and condensation of water and the role of heat or temperature in all of these                   |

### Selecting the Content Related to Specific Test Items

After the content related to each standard was identified, the science content specific to each test item, or the target knowledge for that test item, was defined. We defined the target knowledge of a test item as that portion of the science content knowledge defined by

the standard associated with each test item that was needed to answer the particular test item. For example, one test item concerned the function of leaves in making food for the plant, while another concerned the function of flowers in producing seeds. These structure-function relationships were the target knowledge for by these two items, within the overall content of all plant structure-function relationships defined by Life Science standard 2. A group of researchers with backgrounds in science education, science, linguistics, and teaching determined the target knowledge for each test item through consensus.

Defining the target knowledge for each test item allowed us to look at to what extent the specific target science of a given test item was covered in any given curriculum unit. We reviewed our focal curriculum units for all mentions of activities or readings related to the target knowledge for each of the test items. The sections that follow give detailed descriptions of how each curriculum unit covered the target knowledge for each of our six focal test items.

**Coverage of target knowledge for Flowering Plants.** The target knowledge for Flowering Plants was defined as: “Seeds grow in or come from the flowers of a plant”. Coverage of the target knowledge for this item by unit is shown in Table 3.

Table 3

Coverage of target knowledge for Flowering Plants by unit.

| Curriculum               | Overall coverage of target knowledge   | Activities   |
|--------------------------|--|--|
| FOSS, Structures of Life | The unit covers the fact that seeds start inside flowers but the main emphasis is on seeds being located within fruit. | Seeds start inside flowers: one sentence in a 3-page Science Story.<br>Seeds located within fruit: part of a 3-page Science Story, 2 worksheets, & one activity on harvesting beans from their pods. |

|                                   |  |   |
|-----------------------------------|--|---|
| Insights, Growing Things          | The unit does not cover seeds growing in or coming from the flowers of a plant.  |   |
| STC, Plant Growth and Development | The unit covers the purpose of a flower, its role in seed production, its parts, and the process of pollination within the flower. | In a series of at least six lessons over several weeks, students pollinate their flowers using dead bees, observe & harvest the seed pods after the flowers have died, and discuss the interdependence of bees and their Brassica plants. |

**Coverage of target knowledge for Plant Diagram.** The target knowledge for this test item was defined as: “Structure 3 is a leaf, and leaves make food for the plant”. The coverage of this target science by unit is shown in Table 8.

Table 4

Coverage of target knowledge for Plant Diagram by unit.

| <b>Curriculum</b>                 | <b>Overall coverage of target knowledge</b>   | <b>Activities</b>   |
|-----------------------------------|---|---|
| FOSS, Structures of Life          | The unit covers the identification of leaves, but does not cover how leaves make food for the plant. In fact, the unit overview explicitly states that students can learn a great deal from observing germination and the life cycle of beans without understanding the process of photosynthesis, which is learned in units after Grade 5. | There are lessons on the definition of leaves as flat, green parts of the plant that grow from the stem or up from the roots. |
| Insights, Growing Things          | The unit mentions that the seed has stored food to use until leaves begin their own food production.  | This information is mentioned as part of one 10-minute session.   |
| STC, Plant Growth and Development | The unit mentions that the seed leaves produce food until the true leaves develop.  | The mention of seed leaves producing food is a small part of a lesson on what’s inside a                                      |

|  |   |   |
|--|---|---|
|  | <p>There is no mention of true leaves producing food for the plant.</p> | <p>seed and a lesson about observing leaves. Students make a Brassica model including seed leaves and true leaves (one lesson) and observe the leaves and buds on their Brassica plants (one lesson).</p> |
|--|---|---|

While the units we reviewed do not focus on the fact that leaves produce food for the plant, they do, however, put a lot of emphasis on the role of plants in food production. We felt that it was important to understand how students had learned about the role of plants in producing food, as this may be an important contributor to how they answered the Plant Diagram test item.

Table 5

Coverage of role of plants in producing food for other organisms by unit.

| <b>Curriculum</b>        | <b>Overall coverage of target knowledge</b>   | <b>Activities</b>  |
|--------------------------|---|--|
| FOSS, Structures of Life | In the unit, students learn that people and animals eat seeds as an important part of their diets.                                | One three-page Science Story includes a section on people and animals eating plant seeds.  |
| Insights, Growing Things | The unit covers the fact that seeds have stored food for the plant and the fact that some plant roots are used by humans as food. | There is one 10-minute lesson that includes the fact that the seed has stored food. Students plant bean, corn, and pea seeds. At home, students look for seeds (such as dried beans) that can be soaked & split open to examine (one worksheet). Students also learn that roots are important to humans as food and they find examples of foods we eat that come from roots (one worksheet). Students may bring in root vegetables to eat and read a |

|                                   |   |  |
|-----------------------------------|---|--|
|                                   |   | selection from a book about root vegetables.   |
| STC, Plant Growth and Development | In this unit students learn that plants make pollen and nectar that are food for bees (pp. 65, 68, 69). | Four lessons on the pollination process, in which students use dried bees to pollinate their plants. |

**Coverage of target knowledge for Purpose of Thorns.** The target knowledge for this test item was defined as: “A thorn is a sharp growth on the stem of a plant that can protect the plant from predators.” Table 6 shows the coverage of this target science for the three units included in this review.

Table 6

Coverage of target knowledge for Purpose of Thorns by unit.

| <b>Curriculum</b>                 | <b>Overall coverage of target knowledge</b>  | <b>Activities</b>  |
|-----------------------------------|--|--|
| FOSS, Structures of Life          | The unit does not cover thorns. However, means of protection for the seed are mentioned. | Two Science Stories mention the seed coat and the fruit as protection for the seed. The Science Stories are three-page stories meant to be read aloud to students. |
| Insights, Growing Things          | The unit does not cover thorns or plant protection.                                      |  |
| STC, Plant Growth and Development | The unit does not cover thorns or plant protection.                                      |  |

**Summary of coverage of target knowledge for focal life science test items.**

Overall, these units provide lessons on plant growth, as well as some of the structure/function relationships listed in Life Science Standard 2. However, each unit has a different emphasis and no one unit covers all of the structure/function relationships for each part of a plant.

Thorns are never discussed as a means of protection for the plants, and none of the plants that the students work with in these units have thorns on them. Leaves are discussed in relation to

the process of plant growth, in that seed leaves develop before the true leaves grow, but not rarely in relation to the production of food for the plant. The location and function of the seeds is most thoroughly described, as the seeds are both the beginning and end product of the plant growth. However, only two units describe the growth of seeds in flowers, and there is a greater emphasis in these units on seeds being located in fruits than on their location within the flowers.

**Coverage of target knowledge for Freda’s Swimsuit.** We defined the target knowledge for Freda’s Swimsuit to be the following: “Adding heat to water makes it dry (or change from a liquid into a gas) faster”. Additional knowledge that is helpful for answering the Freda’s Swimsuit test item include: the role of evaporation in drying, what additional factors influence the rate of drying, and the definition of “water vapor”.

Table 7

Coverage of target knowledge for Freda’s Swimsuit by unit.

| <b>Curriculum</b>          | <b>Overall coverage of target knowledge</b>  | <b>Activities</b>  | <b>Coverage of additional knowledge</b>  |
|----------------------------|--|--|--|
| FOSS, Water                | There is emphasis on the idea that higher air temperature leads to faster evaporation.                                     | The unit contains one lesson on the effect of air temperature on evaporation, using an experiment with wet paper towels in which the paper towel in the warmer location is expected to dry faster. | There is one lesson on the effect of surface area on evaporation. There are approximately 90-110 minutes of lessons that cover the topic of water vapor. |
| Insights, Changes of State | the unit emphasizes that evaporation is associated with heat, and faster evaporation is associated with higher temperature | There are two lessons on the effect of air temperature, on alcohol drops’ rate of drying. One lesson concerns  | The lessons on alcohol drops drying also include the effects of surface area, and blowing  |

|              |  |   |   |
|--------------|--|---|---|
|              |  | how sweat takes heat from our skins by evaporating and one lesson involves heating dirty water to make the water evaporate.   | on the rate of drying. Two lessons concerning condensation mention water vapor. |
| STC, Changes | This unit suggests that water temperature affects the rate of evaporation of water, with higher water temperatures leading to more evaporation. Drying is not mentioned. | The unit contains one lesson on cups of warm and cold water left uncovered in the classroom. This demonstrates that warm water shows evidence of evaporation (cup covering water has condensation on inside) and cold water does not. |   |

**Coverage of target knowledge for Take Away Heat.** The target science for the Take Away Heat test item is: “Taking away heat from water can cause liquid water to turn into a solid. Take away heat means cool.” There is no additional knowledge needed to answer this test item correctly.

Table 8

Coverage of target knowledge for Take Away Heat by unit.

| <b>Curriculum</b>          | <b>Overall coverage of target knowledge</b>  | <b>Activities</b>  |
|----------------------------|--|--|
| FOSS, Water                | The unit states that water needs to be really cold in order to freeze. The phrase “take away heat” is not used in student activities, but is used in the teacher background section. | One lesson (45 minutes total) on “getting water really cold” by putting it in the freezer and noticing what happens. |
| Insights, Changes of State | The unit includes the statements that freezing is  | One lesson ((90-135 minutes) on water freezing by cooling.   |

|              |   |   |
|--------------|---|---|
|              | equivalent to solidifying and that freezing happens by cooling. The phrase “take away heat” is not used in student activities, although it is included in the background for the teacher. In student activities, “cooling” is used to describe the process of removing heat from an object. | Students are expected to learn that “Liquids freeze into solids when they are cooled.”  |
| STC, Changes | The unit covers freezing, which happens in the freezer and is associated with a feeling of cold, but is explicitly linked neither to cooling nor to taking away heat. The teacher background section mentions that the cold temperature of the freezer removes heat energy from the water.  | One lesson on putting water into ice cube trays and then into the freezer and noticing what happens. Two half-lessons discussing pictures and story about melting and freezing. |

**Coverage of target knowledge for Justin’s Jars.** For this test item, we defined the target knowledge to be: “Adding heat to liquid water causes it to turn into a gas. The sun is a source of heat. For water, turn into a gas means turn into water vapor”.

Table 9

Coverage of target knowledge for Justin’s Jars by unit.

| <b>Curriculum</b> | <b>Overall coverage of target knowledge</b>  | <b>Activities</b>  |
|-------------------|--|--|
| FOSS, Water       | The unit includes an activity on the effect of air temperature on evaporation, but sunlight is not necessarily included in this investigation. Evaporation is described as turning into a gas. | The unit contains one lesson on effect of air temperature on evaporation through an experiment with wet paper towels. This may or may not involve sunlight depending on the locations the teacher chooses for the paper towels. There is one lesson on the effect of surface area on |

|                            |   |   |
|----------------------------|---|---|
|                            |   | evaporation.  |
| Insights, Changes of State | Overall, this unit emphasizes that evaporation is associated with heat, and faster evaporation is associated with higher air temperature. Evaporation is described as turning into a gas. | The unit contains one lesson on the effect of air temperature on the rate of drying of alcohol drops. Depending on where students place the drops, they may encounter the role of the sun in adding heat to the drops and speeding up drying. The lesson also contains one lesson on how sweat takes heat away from our skin when it evaporates and one lesson involves heating dirty water to remove it from impurities. |
| STC, Changes               | The unit includes an activity on the role of water temperature in evaporation. There is no mention of the effect of the sun. Evaporation is described as turning into a gas.              | The unit contains one lesson on cups of warm and cold water left out. Warm water shows evidence of evaporation (cup covering water has condensation on inside) and cold water does not.   |

**Summary of coverage of target knowledge for three focal Physical Sciences test items.** Overall, these three units focus more time and attention on evaporation (related to Freda's Swimsuit and Justin's Jars) than on freezing (related to Take Away Heat). The messages students get about evaporation are likely to vary depending upon which unit they use and how the particular activities proceed. A number of activities in the reviewed units involve students or teachers choosing various locations for objects intended to dry, so that sunlight may or may not be considered as a factor related to evaporation. Overall, evaporation was related to temperature of the liquid or the surrounding air, with higher temperature regions leading to faster drying or more evaporation. However, the relationship between heating by the sun and drying was not clear in most of these lessons. In addition, the

focus of some lessons on the temperature of the water and its role in drying may suggest to students that, for the Freda's Swimsuit test item, the temperature of the water in the pool should influence the rate at which Freda's swimsuit dries, which is incorrect according to this test item. In the lessons on cooling that leads to freezing, the language of "taking away heat" was not used in student lesson plans, although it was present in the background sections for teachers.

### **Discussion**

The curriculum units we reviewed covered the target science of the standards and of the focal test items to varying degrees and in varying ways. The Life Sciences curriculum units seemed lacking in coverage of the definition and function of thorns and the process of production of food for the plant in the leaves, which are two of the main target knowledge topics of our focal test items related to Life Science Standard 2. The Physical Sciences curriculum units had more coverage of the target knowledge for each test item, but there was variability in the activities used to explore this target knowledge, and thus there is likely to be variability in the conclusions that students can draw from these activities about the role of heat in any given change of state.

Our review of the curricula gave us some insight into what may be taught in classrooms and how the science content related to each standard is presented to both teachers and students. While we cannot claim to know how the science content is actually presented in any specific classroom without conducting direct observations of classroom activities, the curricula we reviewed represent a range of lessons and activities that one could expect to find in a 3<sup>rd</sup> to 5<sup>th</sup> grade science classroom. We have found some discrepancies between the science that is taught and the science targeted by the test items, and we believe that these

discrepancies may cause difficulties for students. If the most highly-regarded and frequently used curricula don't use the same language or use language in the same way (e.g., "heat is taken away" or "make food") as on the science test items on the MCAS, then it becomes more challenging for students to interpret these test items at the item writers intend. In addition, if the content of test items is not included in these curricula, then teachers who are making their best efforts to cover all the material specified in the standards will not have prepared their students to answer these items. In those cases (e.g., the function of thorns on a plant and the role of leaves in photosynthesis), the only students who can be expected to answer such items correctly are those who have learned this content outside of school, thus disadvantaging those students without such opportunities. Situations like those described above undermine the purpose and the validity of the MCAS as a measure of the science content students have learned in school (Massachusetts Department of Elementary and Secondary Education, 2010).

Especially in the case of high stakes testing, it is imperative that standards, assessments, and curricula be aligned in order for students' test scores to constitute valid measures of the science content they have learned in school, as opposed to other unrelated factors, also known as sources of construct-irrelevant variance (Haladyna & Downing, 2004). Our curriculum study has informed our larger interview study by revealing gaps in the alignment of standards and curricula that may contribute to test results that do not accurately portray the knowledge students gain during their classroom experiences.

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### References

- Carolina Curriculum. (2010). *Carolina Curriculum Correlation to Massachusetts Science and Technology/Engineering Curriculum Framework: Grades K-8*. Retrieved from Carolina Curriculum website: <http://www.carolinacurriculum.com/services/states/MA/pdfs/science/ma.pdf>
- Delta Education. (2008). *Full Option Science System K-8 Correlation to Massachusetts Science and Technology Curriculum Framework*. Retrieved from Delta Education website: <http://www.delta-education.com/science/foss/correlations/Massachusetts.pdf>
- Education Development Center. (2003a). *Insights: An Elementary Hands-On Inquiry Science Curriculum*. Dubuque, IA: Kendall Hunt.
- Education Development Center. (2003b). *Insights: An Elementary Hands-On Inquiry Science Curriculum: Growing Things*. Dubuque, IA: Kendall Hunt.
- Haladyna, T. M., & Downing, S. M. (2004). Construct-irrelevant variance in high-stakes testing. *Educational Measurement: Issues and Practice*, 23(1), 17-27.
- Kendall Hunt. (2009). Correlation between Insights Curriculum and NSE Content Standards Retrieved April, 28, 2009, from <http://www.kendallhunt.com/index.cfm?PID=219&PGI=137>
- Lawrence Hall of Science. (2005a). *Full Option Science System*. Nashua, NH: Delta Education.
- Lawrence Hall of Science. (2005b). *Full Option Science System: Structures of Life*. Nashua, NH: Delta Education.
- Lawrence Hall of Science. (2010). Great Explorations in Math and Science, 2010, from <http://lhsgems.org/aboutgems.html>
- Massachusetts Department of Education. (2003). Massachusetts Comprehensive Assessment System: Test Questions, retrieved 2007, from <http://www.doe.mass.edu/mcas/testitems.html>
- Massachusetts Department of Education. (2004). Massachusetts Comprehensive Assessment System: Test Questions, retrieved 2007, from <http://www.doe.mass.edu/mcas/testitems.html>
- Massachusetts Department of Education. (2005). Massachusetts Comprehensive Assessment System: Test Questions, retrieved 2007, from <http://www.doe.mass.edu/mcas/testitems.html>
- Massachusetts Department of Education. (2006). *Massachusetts Science and Technology/Engineering Curriculum Framework*. Massachusetts Department of Education Retrieved from <http://www.doe.mass.edu/frameworks/current.html>.
- Massachusetts Department of Elementary and Secondary Education. (2010). What is tested on MCAS? Retrieved July, 2010, 2010, from <http://www.doe.mass.edu/mcas/overview.html?faq=1>

- National Academy of Sciences and the Smithsonian Institution. (1996). *Resources for Teaching Elementary School Science*. Washington, D. C.: National Academy Press.
- National Science Resources Center. (2002). *Science and Technology for Children*. Washington, D. C.: National Academy of Sciences.
- Noble, T., Suarez, C., Rosebery, A., O'Connor, M. C., Warren, B., & Hudicourt-Barnes, J. (2012). "I never thought of it as freezing": How students answer questions on large-scale science tests and what they know about science. *Journal of Research in Science Teaching*, 49(6), 778-803.
- NSRC. (1991). *Plant Growth and Development*. Washington, D.C.: Smithsonian Institution-National Academy of Sciences.
- Rosebery, A., O'Connor, M. C., Noble, T., Suarez, C., Hudicourt-Barnes, J., & Warren, B. (2010). *Understanding Children's Performance on Multiple-Choice Items in Achievement Tests in Science* (Technical Report Number 1). Retrieved from Chèche Konnen Center website: <http://chechekonnen.terc.edu/publications.html>