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AUTHOR	Anderson, Susan Smetzer; Farnsworth, Valerie
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ABSTRACT

This document describes the research project Modeling for Understanding in Science Education (MUSE) which focuses on the improvement of high school students' learning. MUSE research investigated how lower and high achieving students learned to reason, inquire, present, and critique scientific arguments in a genetics course taught during the spring and fall in 1997. Scientific Modeling stands as the main frame for MUSE projects and is described as a natural process for teachers and students. (YDS)

High School Students "Do" and Learn Science through Scientific Modeling.

Susan Smetzer Anderson
Valerie Farnsworth

NATIONAL CENTER FOR IMPROVING STUDENT LEARNING & ACHIEVEMENT IN MATHEMATICS & SCIENCE

inBrief

K-12 Mathematics & Science
RESEARCH & IMPLICATIONS
FOR POLICYMAKERS, EDUCATORS & RESEARCHERS
SEEKING TO IMPROVE STUDENT LEARNING & ACHIEVEMENT

ABOVE: **High school students work on a genetics model under the eye of science pioneer 'Gregor Mendel,' who paid a visit to Sue Johnson's class.**

HIGH SCHOOL STUDENTS "DO" AND *learn* SCIENCE THROUGH *Scientific Modeling*

Significant insights about student learning in science are emerging from a 12-year research project conducted by high school teachers and researchers affiliated with the National Center for Improving Student Learning and Achievement in Mathematics and Science. With collaborating teachers, researchers have developed new courses based on scientific modeling principles. The research project, Modeling for Understanding in Science Education (MUSE), is yielding challenging science curricula[1] and insights about instruction and assessment.

Conducted at Wisconsin's Monona Grove High School, which serves rural and suburban students, the long-term studies indicate ways science instruction can be strengthened to meet reform goals.

Evidence indicates that student understanding of challenging science content measurably increases with MUSE-based curricula. Through courses focusing on astronomy, genetics, and evolutionary biology, students learn to ask astute questions about data and to present scientific arguments to classmates as they collaboratively build explanatory models. Importantly, student understanding appears to increase because in-depth scientific inquiry replaces more typical curricula that often require students to survey broad swaths of content.

The learning outcomes sought in MUSE-based courses reflect the goals set forth in *Benchmarks for Science Literacy* (1993) and the *National Science Education Standards* (1995). *Benchmarks* and *Standards* indicate that students should be familiar with key science concepts and able to apply acquired reasoning skills to real-world problems. In addition, students should be able to make links across science concepts. The scientific modeling strategies employed in MUSE are geared to facilitate students' learning, reasoning, application and linking of concepts. Research and learning outcomes in two 1997 MUSE-based genetics classes are outlined here.

RESEARCH FOCUS:
Two MUSE Genetics Classes

Researchers Jennifer Cartier and Jim Stewart, alongside teacher-researcher Sue Johnson, have collaborated on several MUSE research studies. This issue of *in Brief* reports on a study of high school students' learning genetics during two elective courses taught by Johnson during spring and fall 1997. These courses attracted a representative group of junior and senior students. Importantly, the researchers observed how typically lower-achieving and higher-achieving students learned to reason, inquire, and present and critique scientific arguments. They also were able to identify classroom factors that enabled teachers and students to more fully engage in scientific inquiry and modeling.

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[1] *Curricula, as outlined here, reflects the definition included in the 1996 National Science Education Standards (p. 111) "Curriculum is the way content is organized and emphasized; it includes structure, organization, balance, and presentation of the content in the classroom." As NCISLA researchers study student learning, they concurrently study how the curriculum can be structured to support desired learning outcomes.*

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THE MODELING CLASSROOM: *Doing Science to Learn Science*

Just as the National Science Education Standards *assert "learning science is something that students do, not something that is done to them" (1995, p. 20), MUSE-based courses involve students in doing science.*

Scientific modeling is the centerpiece of the MUSE project and provides students and teachers a framework for learning about key concepts and causal processes implicit in scientific phenomena. As defined by Cartier and colleagues, a scientific model is a set of ideas that describes a natural process and can be used to explain a specific set of phenomena (Cartier, Rudolph & Stewart, 1999; Harrison & Treagust, 1998).

In the modeling classroom, students collaboratively generate data, seek patterns in the data, and then develop scientific models that explain the data and have predictive power. Science content and process are integrated, and students learn to develop and justify scientific models as they do scientific inquiry. In the MUSE-based genetics class, students investigate and develop models to explain inheritance patterns seen in data.

FEATURES OF THE *Modeling Classroom*

- **Instruction emphasizes** students' use of **scientific models** to understand, illustrate, and explain key genetics ideas and data.
- **Students form a scientific community** to learn about, present, and discuss genetics models with their peers. Students collaboratively gather data, discuss, observe, and present scientific arguments for critique.
- **Students hone their reasoning skills** through judging their own and other students' explanatory models. Students evaluate models for their fit with data,their predictive power, and their consistency with other scientific models or concepts.
- The **teacher assumes the role of co-inquirer** in the classroom, engaging the students in scientific inquiry and invigorating their investigations through questions and class discussions.
- The **teacher continuously assesses students' understanding** to determine the direction of instruction. Through iterative, ongoing assessment of individuals and groups, the teacher gives students constructive feedback to direct their learning.

ASSESSMENT: *Formative and Ongoing*

Assessment in MUSE is formative — informing instruction — not only post hoc, to assign a grade. The teacher uses take-home exams, short-answer tests, class discussions, and presentations — all based on students' modeling work — to gather authentic assessment material. On a day-to-day basis, the teacher pays attention to student thinking and iteratively assesses students to gauge their understanding of scientific data and models. This day-to-day activity informs the teacher's instruction decisions, for the class and individual students. Using authentic and formative assessments, the teacher provides regular feedback to students to reinforce and direct their learning.

FINDINGS: *Student Learning*

Evidence collected across the two 1997 genetics classes indicates that diverse students learned and excelled with this type of instruction. Cited below are findings from Cartier's study and comments contributed by Cartier and teacher-researcher Sue Johnson.

Specifically, students in Cartier's study were able to construct, revise, and assess their own scientific models through collaborative inquiry and critique. As the students conducted data-driven inquiry using Calley and Jungck's (1997) computer software (Genetics Construction Kit), they were challenged to account for different inheritance patterns in hypothetical fruit flies. Through collaborative investigations, many students came to a fuller understanding of the nature of science and scientific modeling (see *In-class Snapshot*, page 3), as well as a rich understanding of classical transmission genetics.

Interestingly, researchers and teachers involved in MUSE note that improvements in learning and understanding are sometimes most dramatic in students who do not score as well in "traditional" classes. Johnson comments that students who receive high grades in traditional classes might be accustomed to writing down a correct answer and moving on to another topic. "Some of these students can become frustrated with scientific inquiry because it requires them to be persistent in developing a workable model," states Johnson.

In the genetics class, students are challenged to develop a workable model that explains data about inheritance patterns and is consistent with a range of scientific concepts and processes. Similar to scientists, students very often propose scientific models that initially do not fully explain the data and then have to persist in working with the data to develop a scientific model with explanatory power. The scientific modeling experience forces students to confront their own depth of understanding — or lack thereof.

Cartier asserts in her study that students' understanding of scientific inquiry and argumentation skills increased as they examined conceptual consistency between their proposed models and accepted scientific knowledge. Also, scientific modeling provided an avenue for students to strengthen their analytical skills. These improvements are important, because research indicates that while students might be able to recite definitions of science concepts when tested, they might not *understand* the concepts and their place within a larger body of science. (Cartier, 1999; see also Frederickson, White & Gutwill, 1999) If instruction fails to build understanding, students' analytical skills are likely to remain underdeveloped.

In sum, across the life of the course, students came to see scientific models as a means by which they could explain and predict inheritance pattern data. Data collected through various assessment exercises also showed that students' understanding of the utility of scientific models grew dramatically across the 9-week course. Overall, modeling was shown to support students' growth in understanding of genetics concepts, as well as of scientific inquiry and reasoned argumentation.

IMPLICATIONS: *Reform of Science Instruction*

Cartier's research has serious implications for the reform of science instruction and curriculum.

First, this research confronts the question: How can we equip students to think critically and to engage in scientific inquiry? Scientific modeling appears to hone the very skills set forth as desirable in the *National Science Education Standards* (1996), the *Benchmarks for*

Science Literacy (1993), and the U.S. House Committee on Science monograph *Unlocking Our Future: Toward a New National Science Policy* (1998).

Benchmarks and *Standards* call for a science curriculum that engages students in intellectually challenging inquiry, similar to that pursued in professional disciplines. The science instruction outlined here, which introduces students to data-rich inquiry and explanatory models, enhances students' knowledge and reasoning skills — potentially to their long-term advantage.

Second, Cartier's research provides decision makers and educators insight into ways school science can be altered to meet reform goals. For schools to adopt a model-based approach to science instruction, administrators and teachers will need to rethink the focus of their science classes and the roles of teachers and students in the classroom. For example, this type of instruction compels students to take a proactive role in their learning. "In this class, students learn by doing, and it sticks," states Johnson, whose students have told her that her class(es) have helped them to succeed in their college science courses.

Furthermore — and importantly — teachers wanting to change their instructional approach will need time and appropriate professional development and support from school administrators and colleagues. For example, teachers will need time to explore the modeling approach themselves and to integrate model-based instruction into their curricular repertoire.

Johnson points out one of the challenges her colleagues face if they choose to adopt MUSE. "At first, it is difficult to give up being the 'knowledge reservoir,'" says Johnson. "However, it wasn't as difficult as I thought it would be. The first one or two times that I taught the genetics course I had to watch what I said when talking to student groups [to avoid telling them problem solutions], but after a while it wasn't a problem at all . . . I felt so strongly about what we were doing, and the benefits are great. Students now experience 'aha!' moments in my classroom."

ABOVE: ***We got it!*** **Students celebrate when their proposed genetics model accurately predicts eye color.**

NEXT STEPS: *Supporting Reform*

Reform-minded school administrators and teachers are likely to see the benefits of scientific modeling for student learning and understanding. However, they are also under considerable pressure to assure that students score well on standardized tests. According to science education researcher Jim Stewart, standardized tests often give priority to science content coverage and neglect modeling strategies. As leaders and educators consider implementing model-based science curricula, they will need to address the assessment challenge.

In addition, researchers, educators, and leaders will want to determine which science content areas (out of the vast amount of science students can learn) should be given priority in student learning — not only at the secondary level, but at the primary level as well. Having accumulated several years' worth of in-class research results, Center researchers can share insights about K-12 curricular priorities and assessment with policymakers and educators interested in research-based science education reform. Center researchers continue to work on several reform-related questions in their classroom-based research.

For More Information About MUSE

Easy-to-access research reports regarding MUSE are listed in the reference section of this *in Brief* and are available at the national Center's web site at www.wcer.wisc.edu/ncisla. A web site featuring MUSE-based teacher tools for secondary school genetics, astronomy, and natural selection is under development and should be accessible this winter.

Researchers Jennifer Cartier and Jim Stewart can be reached through the National Center for Improving Student Learning and Achievement in Mathematics and Science at the University of Wisconsin-Madison, 1025 W. Johnson St., Madison, WI 53706; (608) 265-6240; E-mail: ncisla@mail.soemadison.wisc.edu.

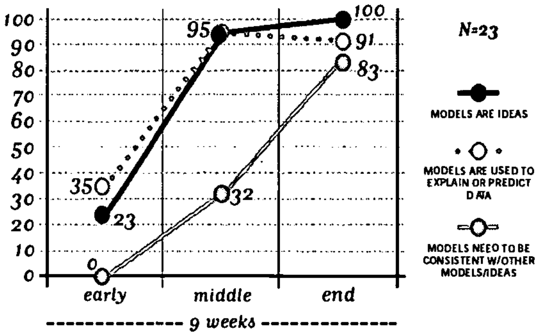
IN-CLASS SNAPSHOT: *Students Gain Understanding of Scientific Modeling*

Assessments conducted throughout the 9-week genetics course showed that students' conceptions of scientific models became much more sophisticated and comprehensive as they progressively developed models to explain inheritance patterns apparent in computer generated fruit fly data.

At the beginning of the course, students defined scientific models as **replicas** (or pictures) of ideas. However, this changed dramatically by the end of the course, when most students came to a "scientific" view of models. In the scientific view, models **are** ideas. They are used to explain and predict data and are necessarily consistent with other established scientific models. Because modeling is at the core of scientific inquiry and theory development, researchers found students' growth in understanding of scientific modeling encouraging. The following graph clearly shows the shift in student understanding of scientific models from the beginning to the end of the course.

NOTE: Percentages reflect composite scores on journal assignments, exam questions, and interviews, and do not reflect data collected in field notes or classroom discussions. The drop at the end of the course (from 95% to 91%) in "Models are used to explain or predict data" is not thought to be statistically significant. Total number of students in the 1997 class featured here is 23.

FIGURE 1. *Student Understanding of "Scientific" Point of View Increased Throughout the Course*



NATIONAL CENTER FOR IMPROVING STUDENT LEARNING & ACHIEVEMENT IN MATHEMATICS & SCIENCE

inBrief

K-12 Mathematics & Science
POLICY CONSIDERATIONS

Modeling for Understanding in Science Education (MUSE)

Several implications arise from Jennifer Cartier's (1998) study of high school students using Modeling for Understanding in Science Education (MUSE) in two 1997 genetics classes. Specifically, MUSE requires a reorientation of teacher practice, clarification of science learning goals, an emphasis on learning narrower (in-depth) slices of content rather than broad content coverage, and the establishment of classroom norms that support collaborative inquiry. To support these changes, policymakers will want to consider:

Communication and Support

Teachers, administrators, parents, and policymakers need to communicate about — and jointly support — the goals for student learning in science. Ideally, science instruction goals would stipulate that students learn science content and scientific process as integrated practice. MUSE, properly implemented, integrates content and process, and gives students an introduction to real-world scientific practice. Speaking from experience, science teacher-researcher Sue Johnson indicates that parents' support has been a factor in the success of the MUSE genetics curriculum.

Classroom Environment

Modeling for understanding in science requires that students function as a scientific community — collaboratively. Although MUSE can be adopted in classes of any size, smaller classes provide teachers more opportunities to engage with students and assess their learning.

Professional Development

Teachers implementing MUSE will require time to incorporate modeling strategies into classroom curricula. Because many teachers have not experienced scientific inquiry or research during their own education, they will need experience in scientific modeling, as well as professional support, as they alter their pedagogical and assessment strategies. They might also need to develop more sophisticated content knowledge.

SPECIFIC SUGGESTIONS FOR PROFESSIONAL DEVELOPMENT

- Cartier and researcher Jim Stewart indicate that **teachers are likely to benefit from summer programs or long-term involvement with university science education experts** as they adopt MUSE. One-shot or one-day professional development programs will not be adequate to build and support teachers' understanding of scientific modeling. Regular contact between education researchers and teachers can support teachers' transition to a scientific modeling classroom. (Throughout its 12-year existence, the MUSE project has forged strong teacher-researcher collaborations. These collaborations have yielded new curricula that appropriately integrate scientific processes with content. The collaborations have also helped teachers to learn and integrate scientific modeling strategies into their instructional repertoire.)
- **Policymakers should consider supporting school-university research and professional development partnerships.** Researchers at local universities are an often untapped resource for teachers and schools. School-university partnerships might be one way to advance both teachers' professional development and broader research in MUSE.
- School administrators might consider **encouraging the development of collaborative science teacher communities** that provide teachers opportunities to interact with one another about their use of modeling strategies and the focus of their school science program. Most of the science teachers at Monona Grove High School, the site of MUSE research, have developed such a community over several years. Center research is in progress regarding the functions of this teacher community and its administration.

Technology

Computer programs can assist instruction *if they are relevant*. Resources used for the MUSE genetics course include Calley and Junck's (1997) Genetics Construction Kit – a computer simulation by which students track inheritance patterns in hypothetical organisms. Computer simulation programs such as these can support students' learning by giving students a chance to generate data and test their predictions.

Standardized Tests

Although not a focus of the MUSE study, Cartier and Stewart are concerned that high-stakes or standardized tests might discourage teachers and schools from adopting MUSE. According to Stewart, such tests often fail to adequately gauge students' grasp of both science content and scientific processes. Nor do the tests provide students opportunities to demonstrate their understanding of modeling strategies.

In addition, model-based instruction requires teachers and students to focus on understanding narrower slices of science content. If standardized tests give priority to content coverage and neglect modeling strategies, teachers (reasonably) might be less likely to adopt the MUSE strategy.

In short, together with educators and others, policymakers will need to consider the goals of science instruction and the importance of scientific modeling, and discern the implications of these for assessment.

For more information about this study or the MUSE research project, contact Jennifer Cartier or Jim Stewart at the National Center for Improving Student Learning and Achievement in Mathematics and Science, University of Wisconsin-Madison, 1025 W. Johnson Street, Madison, WI 53706, (608) 265-6240. E-mail: ncisla@mail.soemadison.wisc.edu. Web site: http://www.wcer.wisc.edu/ncisla.

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K-12 Mathematics & Science
TEACHING CONSIDERATIONS
Modeling for Understanding in Science Education (MUSE)

Teachers and school administrators will need to consider the following if they choose to implement Modeling for Understanding in Science Education (MUSE) in their classrooms:

Tasks

THE TEACHER WILL NEED TO:

- Provide students with **an example** of a scientific model (e.g., Mendel's model of simple dominance in genetics) as a starting point for discussions about scientific concepts and models.
- When possible, have students **observe** natural phenomena and collect their own data. Teachers can also provide them with rich data sets and/or utilize technology to generate such data.
- Ask students to **look for patterns** in data.
- Ask groups of 3-4 students to **develop models** that explain the data and predict additional experimental outcomes.
- Engage students in **discussions** of the nature of scientific models as they develop and revise models.
- Encourage students to **judge** their models in terms of their explanatory power, predictive adequacy, and consistency with other scientific models or concepts.
- Engage students in the **exploration** of relationships between different models and their underlying processes, many of which students might have learned about in previous classes.
- Provide opportunities for students to **communicate** their own ideas and **critique** those of their peers.

Instruction

THE TEACHER WILL NEED TO:

- Take on the role of **"co-inquirer"** rather than distributor of information.

ABOVE: Teacher-Researcher Sue Johnson looks on as a high school student conducts a DNA experiment.

- Emphasize that students must be **active learners** as they develop models to account for scientific phenomena.
- Facilitate **group discussions** so that they mirror those in scientific communities, enabling students to reach conclusions about data patterns and to judge the adequacy of their explanatory models.
- Be mindful that students need to learn how to construct and defend **scientific arguments.** A student might achieve this learning outcome even if he/she has not developed the "correct" (currently held) model.
- Be aware of the particular **needs of individual students.** Some students might require special encouragement to participate in discussions or need a framework to organize their learning. For example, a teacher might encourage students to ask themselves on a regular basis: "What am I learning about genetics? About scientific inquiry? About scientific modeling?"

Assessment

THE TEACHER WILL NEED TO:

- Regularly **probe students' understanding** of the need for consistency between models and other scientific knowledge and the need for models to explain and predict data.
- Use **assessment as a tool for developing instruction** based on students' levels of understanding.
- Employ **various forms of authentic assessment,** such as portfolios, journal assignments, and oral assessments.
- Make use of **different formats** to assess students' skills and knowledge levels (e.g., short-answer tests, take-home exams, modeling exercises, presentations, and class discussions).

Learning Environment

THE TEACHER WILL NEED TO:

- Assure the **physical space** of the classroom is conducive to collaborative work.
- Establish classroom norms to create an **active learning environment** and explain to students that they will be evaluated on their involvement in the classroom research community and their work in formulating and communicating ideas to their peers.
- Establish **norms of reasoned argumentation** such that students must offer supporting evidence for knowledge claims and demand such evidence from their peers.

For More Information

MUSE genetics curricula (as well as astronomy and evolutionary biology resources) will be placed on the NCISLA web site in the Teacher Resources section (http://www.wcer. wisc.edu /ncisla/teachers). Reports about the genetics research are now available at the NCISLA web site (Publications section) and can be downloaded in PDF format. (See the Reference section of this *in Brief* for report titles.)

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NCISLA Director: Thomas P. Carpenter

NCISLA Associate Director: Richard Lehrer

NCISLA Communication Director:
Susan Smetzer Anderson

Writers: Susan Smetzer Anderson &
Valerie Farnsworth

Designer: Kristen Roderick

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Wisconsin Center for Education Research
School of Education, University of Wisconsin-Madison
1025 West Johnson Street, Madison, WI 53706

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Signature: Susan Smetzer Anderson

Printed Name/Position/Title: Susan Smetzer Anderson, Communication Director

Organization/Address: Nat'l Ctr. for Improving Student Learning and Achievement in Mathematics and Science

Telephone: 608-265-5630

FAX: 608-263-3406

E-Mail Address: anders90@facstaff.wisc.edu

Date: 3/12/02