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Introduction

I would like to begin by thanking you, Mr. Chairman and members of the Committee, for inviting me to provide testimony about the importance to the nation of inquiry-based science education. I would like to thank you in particular for your previous support for the role that science agencies such as NOAA, NSF and NASA play in promoting and improving science education in the United States. I believe you can be very proud of the work that those agencies are doing on a daily basis to improve the lives of young people, to provide assistance to teachers, and to continually improve the quality of our future workforce. It is my sincere hope that you will continue and even increase support for the education programs of these agencies. If I leave you with only one message today, it is that science agencies such as NOAA, NSF and NASA must play a leadership role in the improvement of science education. The type of high quality science education that is required to bring about science literacy for all Americans and to prepare the next generation of scientists depends on the direct involvement of today's scientists. Therefore science agencies must have the mandate and the funding to devote significant intellectual and human resources to the endeavor of science education.

I am the Associate Director of the Lawrence Hall of Science at the University of California, Berkeley. I have happily worked there since 1991. **Lawrence Hall of Science (LHS)**, the university's public science center, is a national leader in the development and support of science and mathematics instructional materials for grades preK-12. LHS creates programs, tools and approaches that are replicated, scaled up and disseminated nationally. LHS provides professional development to over 20,000 teachers and school administrators each year, and one in five children in the U.S. uses instructional materials developed at LHS. I invite you to watch a short video about LHS at http://www.lawrencehallofscience.org/about.

NOAA-Sponsored Ocean Sciences Curriculum Sequence, Grades 3-5

I am here today to share with you a NOAA –sponsored project that I direct, our first early indications of its effectiveness, and how it fits into a larger constellation of inquiry-based science education reform efforts supported by NOAA, NSF and NASA, and carried out by institutions such as Lawrence Hall of Science. The project I would like to share is the development of an *Ocean Sciences Curriculum Sequence for Grades 3-5,* funded by the NOAA Office of Education, Environmental Literacy Grants program. This grant created a partnership between the Lawrence Hall of Science Center for Ocean Sciences Education Excellence, Rutgers University and a curriculum publisher, Carolina Biological Supply Company. The project addresses the critical need to provide students with inquiry-based experiences related to the big ideas in ocean sciences. We know that nationwide, even in coastal states, despite the important role that the ocean plays in driving earth systems and influencing our history, culture and economy, concepts about the ocean are not commonly taught in grades K-12. This project will create an unprecedented Ocean Sciences Curriculum Sequence for Grades 3-5, that will provide students with 25 hours of instruction about ocean concepts that are aligned with state and national science education standards. It is anticipated that this new Sequence will become the most widely used ocean-focused science education curriculum nationwide at the elementary level. The materials will provide teachers with a standards-based tool for teaching basic science using the ocean as a compelling integrating context. The materials will be grounded in current research on teaching and learning and designed to connect to the *National Science Education Standards*, *Ocean Literacy: The Essential Principles of Ocean Sciences K-12*, and to a large sample of state science standards. The activities were developed with rigorous input from a team of research scientists, science educators and educational evaluators and researchers. They were thoroughly pilot tested by the developers in local classrooms in Berkeley, California, then field-tested last fall by 70 teachers nationwide to ensure their effectiveness and broad applicability. We are just now analyzing the data we received from teachers and students during the field test in order to revise the final version of the materials. The finished product will include print materials for teachers, with inquiry-based learning activities, a multi-media DVD, student readings and data sheets, curriculum-embedded assessments, and commercially available materials kits that will allow the materials to be adopted by whole school systems and/or states. No comparable ocean sciences curriculum materials are currently available.

I mentioned that the materials we are developing engage students in the process of inquiry. I'll discuss in greater depth later in my testimony what I mean by "inquiry," but for now, let me provide you with an example from the Ocean Sciences Curriculum Sequence for Grades 3-5. One of the most important concepts that we want students to understand is that, "Most of Earth (about ¾) is covered by the ocean." This concept is important because it underlies students' subsequent more abstract understandings that the ocean is a major influence on weather and climate, that most of the oxygen on Earth was produced in the ocean, that most of the living space on Earth is in the ocean, that most major groups of organisms live only in the ocean, that most rain comes from water that evaporated from the ocean, etc. It seems like a straightforward concept, "Most of Earth is covered by the ocean." Straightforward, that is unless you're a 9-year old who has been living on land your whole life and staring at classroom wall maps showing Mercator projections that greatly distort the continents which are always shown in bright colors. We have learned that simply telling students that most of Earth is covered by the ocean is not enough to undo their lifetime of contradictory experience. In the very first session of our curriculum, we have students discuss with a partner how much of Earth they think is covered by land versus water. Then each pair explores a small inflatable globe to look themselves for evidence to answer that question. They try to trace a path on land around the planet and then try to trace a path on the ocean around the planet. They come up with their own forms of evidence, like how many USAs it would take to fill the Pacific Ocean. Finally, we have students collect some data that they can use as evidence. They toss a larger inflatable globe around the room and count the number of times that the right index finger of the catcher is touching land versus water. Inevitably, the data provides evidence that about ¾ of Earth is covered by the ocean. Students write in their notebooks about what the evidence seems to indicate, and how the evidence has helped them to change or support their own personal ideas.

This example is not representative of the most "open" forms of inquiry in which students generate their own questions, develop their own experiments and the criteria for their experimental design, gather and analyze evidence and draw conclusions. But it is inquiry nonetheless, and remember, our materials are designed for 8-10 year olds. The globes activity may not seem like rocket science but here are some of the comments we received from teachers in our field test study. I am including a wide range of comments to open-ended questions so that Committee members will have a sense of the flavor the feedback we received from teachers in extremely diverse socioeconomic, geographic an educational settings:

Huge! Plus, if I had any kids not sure about science before, they have all changed their minds!

This activity had a great impact. It was engaging and the kids were fascinated by how many more of their fingers actually touched water. This was true evidence in their eyes and that is what counts!

it worked well. It gave them a kind of mathematical proof that they needed in order to have a concrete experience.

The recording on the chart reflected what we had already found out so it was a fun way to review and collect more "evidence". VERY effective!

My students loved this activity. We actually performed this twice to see if our results were similar. This was a great way to show evidence of the earth's surface being covered mostly with water.

It was a huge eye opener for them. It made the abstract fraction more real.

It was key because it gave data and evidence to the 70/30 fun fact.

The globe toss was great for the students that needed kinesthetic/hands-on to grasp the concept of the vastness of the ocean.

The hands on globe, the key concepts, and the notebooks really helped to teach the unit. The students will remember this material and be able to use it in the future. I think this also helped them become good thinkers.

It was a good session, I think it helped me to realize that the students have a hard time realizing that they live on a planet, continents, country etc. Something that I assumed they knew.

Evaluating the globe as an example of a model and why models are used in science was effective. Also finding evidence to support more ocean on the Earth than land. Students already knew there was more ocean but challenged by finding evidence to support it. The Global Toss worked very well and was fun!

The globes for student use was extremely effective in showing students the comparison between the globe and Earth. They were amazed that we found more inaccuracies than accuracies. I really enjoyed seeing my students think about whether the Earth should change to being called Planet Ocean and coming up with evidence from the lesson to back up their reasoning.

I think my students have been exposed to the "right" answers but I think they are being exposed to a new way to think about them in this material.

They genuinely thought there was more land than water on the Earth and were surprised that they could not trace a land path around the world but could trace a water path.

They already knew the earth was mostly covered with water but to have the evidence was a powerful addition!

The students believed that the Earth was covered mostly by land because that is what they see each day.

Some kids actually thought different states/countries were in different colors like the model (globe). One thought the words naming the places would be visible from space. I showed them a globe that was more topographical instead of political and I think that helped.

In later instructional sessions in Unit 1, students learn about how scientists at Rutgers University are using autonomous underwater gliders, powered by changes in water density, to collect enormous amounts of never-before-available pressure, salinity and temperature data. One underwater glider just recently completed the first unmanned crossing of the Atlantic Ocean from New Jersey to Spain. Our 3rd through 5th grade students can now use real data collected by RU 27, The Scarlet Knight, to map pressure and temperature changes all the way across the Atlantic. This is another form of inquiry, as students conduct what we call, “secondhand investigations,” that is, they use and analyze data that was collected by someone else.

At the end of each teaching session, we surveyed each teacher involved in the field test to obtain comments and feedback like those above. In addition, we also administered pre and post tests to the students in the field test classrooms. While further research is necessary, we have early indications that while all students improved over the course of instruction, lower performing students show especially strong gains when using the materials. This indicates that the materials have promise for helping to close the “achievement gap.” Below are pre/post assessment scores for Unit 1 only (Unit 1 is comprised of eight hours of instruction).

Student Assessment Results

Students showed significant science content understanding on ALL questions on summative assessment!
Students in lowest-scoring percentile had largest gains!
Multiple choice items:

Content of item	Pre-test correct	Post-test correct	Gain	Gain by lowest-quartile students
One connected ocean	0.61	0.88	0.27	0.45
Shape of ocean floor	0.4	0.94	0.54	0.72
Which parts of ocean move?	0.55	0.73	0.18	0.34
Pattern of temperatures with depth	0.6	0.92	0.32	0.48
Causes of ocean movement	0.34	0.6	0.26	0.31
One connected ocean (pollution)	0.47	0.71	0.24	0.4
Percent of Earth covered in ocean	0.7	0.95	0.25	0.51

Largest gain in shape of ocean floor (1 item)
Smallest gains in movement of ocean (2 items)

Constructed response item- "What would you say if someone said the ocean was layered? Would you agree? Please explain your answer."
Scored on a scale 1-4:
1=no, not layered
2=yes, layered, but no explanation
3=one way layered
4=two or more ways layered

	Pre-	Post-

	test	test
Percent scoring 3 or 4	50.8%	76.2%
Percent scoring 4	24.1%	58.0%
Number mentioning temperature	34	96
Number mentioning light	11	22
Number mentioning salinity	3	14
Number mentioning pressure	3	7

By next year at this time, the Ocean Sciences Curriculum Sequence, Grades 3-5 will be readily available for widespread adoption by school districts nationwide. These materials will also be available to individual interested teachers, but they have been designed with school district adoptions in mind so that they will quickly reach the large, mainstream population of teachers who are bound to use their state approved and district adopted curriculum. I'm pleased to let you know that in January 2010, we also received support from NOAA Office of Education to develop an Ocean Sciences Curriculum Sequence for Grades 6-8. We have already begun the development of this complementary project.

Space Science Sequence, Grades 3-8

The Ocean Sciences Curriculum Sequences are modeled after work that my LHS colleagues have done in the NASA supported, "Space Science Sequence for Grades 3-8" published in 2009. George "Pinky" Nelson was a NASA Astronaut from 1978-1989 and flew on three shuttle missions. He is Director of Science, Math and Technology Education and Professor of Physics and Astronomy at Western Washington University. In his Foreword, he wrote: "My fantasy is that every grade school and middle school will adopt the Space Science Sequence and provide teachers with the professional development and other support to ensure that it is well used. I will use it with preservice teachers in my university as an example of the new generation of curriculum materials…I look forward to the time when students arrive in my astronomy classes at the university with the knowledge and skills taught through these materials. It will change the way I teach because students will arrive prepared to take the next step toward even deeper understanding and appreciation of the Universe."

Lawrence Hall of Science and Inquiry

These curriculum development projects are only two out of dozens of teacher professional development, curriculum development and exhibit development projects currently going on at Lawrence Hall of Science. Since it opened in 1968, LHS has continually had a tremendous impact on the field of science education. In those early years, UC Berkeley Physicist Robert Karplus developed a model of optimal learning called the Learning Cycle that he used as a framework for the development of one of the first and most successful hands-on, kit-based science programs in the post-Sputnik era, Science Curriculum Implementation Study (SCIS). Today, the LHS Full Option Science System (FOSS) is the leading elementary hands-on science program in the country. Currently in development is what we believe will become the science program of the future, Seeds of Science, Roots of Reading, that is designed to synergistically integrate science with reading and writing instruction. SCIS, FOSS, Seeds of Science and many others over the last 42 years were created with support from the National Science

Foundation. Still others over the years have been funded by NASA, and more recently by NOAA.

LHS and a handful of peer institutions around the country with support from federal science agencies have led the way in defining and promoting approaches to teaching science that engage students in doing science, making their own first hand observations, thinking like a scientist and developing scientific habits of mind, such as providing explanations of the natural world that are based on evidence. Our approach provides students with opportunities to engage in respectful discourse, to think critically and to examine alternate evidence. Ultimately, we want all students, not just future scientists, to be empowered to ask their own questions, and be able to puzzle out tentative answers that help them to understand the world and improve their own quality of life. These approaches are collectively described as inquiry-based science education.

There are many definitions of inquiry. The National Science Education Standards from the National Research Council of the National Academy of Sciences describes inquiry this way:

"…Inquiry is an active learning process - something that students do, not something that is done to them." (p.2)

"…Inquiry into authentic questions generated from student experiences is the central strategy for teaching science." (p.31)
And yet, NSES also states that "...this does not imply that all teachers should pursue a single approach to teaching science." (p.2) There are many levels of inquiry-based teaching from "partial inquiry" to "full inquiry." (p.143)

"Essential Features of Classroom Inquiry:
Learners are engaged by scientifically oriented questions.
Learners give priority to evidence, which allows them to develop and evaluate explanations that address scientifically oriented questions.
Learners evaluate their explanations in light of alternative explanations, particularly those reflecting scientific understanding.
Learners engage in discourse to justify and compare their proposed explanations."
(Inquiry and the National Science Education Standards, p 25)

The Exploratorium in San Francisco says:

"Good science education requires both learning scientific concepts and developing scientific thinking skills. Inquiry is an approach to learning that involves a process of exploring the natural or material world, and that leads to asking questions, making discoveries, and testing those discoveries in the search for new understanding. Inquiry, as it relates to science education, should mirror as closely as possible the enterprise of doing real science. The inquiry process is driven by one's own curiosity, wonder, interest, or passion to understand an observation or to solve a problem."
(http://Exploratorium.org/ifi)

There is a growing body of research literature that confirms the effectiveness of inquiry-based science instruction. The literature is typified by a paper recently published in the Journal of Research in Science Teaching entitled, "Inquiry-based Science Instruction—What Is It and Does It Matter? Results from a Research Synthesis Years 1984 to 2002" (Minner, Levy, Century, 2009). The abstract follows:

"Abstract: The goal of the Inquiry Synthesis Project was to synthesize findings from research conducted between 1984 and 2002 to address the research question, What is the impact of inquiry science instruction on K–12 student outcomes? The timeframe of 1984 to 2002 was selected to continue a line of synthesis work last completed in 1983 by Bredderman [Bredderman [1983] Review of Educational Research 53: 499–518] and Shymansky, Kyle, and Alport [Shymansky et al. [1983] Journal of Research in Science Teaching 20: 387–404], and to accommodate a practicable cutoff date given the research project timeline, which ran from 2001 to 2006. The research question for the project was addressed by developing a conceptual framework that clarifies and specifies what is meant by ''inquiry-based science instruction,'' and by using a mixed-methodology approach to analyze both numerical and text data describing the impact of instruction on K–12 student science conceptual learning. Various findings across 138 analyzed studies indicate a clear, positive trend favoring inquiry-based instructional practices, particularly instruction that emphasizes student active thinking and drawing conclusions from data. Teaching strategies that actively engage students in the learning process through scientific investigations are more likely to increase conceptual understanding than are strategies that rely on more passive techniques, which are often necessary in the current standardized-assessment laden educational environment."

We know now that inquiry-based science teaching is effective. We know that when we provide the type of instruction that encourages students to think and behave like scientists, they also construct deeper understandings of the complex ideas of science. If thinking like a scientist is to be the "central strategy for teaching science," as the National Academy of Sciences proclaims, then it clearly follows that the nation's scientists and science agencies must play the leading role in improving science education. NSF, NOAA and NASA must be front and center, not peripheral, in determining what and how our students are taught about science in the future.

NOAA's and NSF's Strategic Use of Limited Funds

NOAA and NSF have both used relatively small investments to engage in strategic field-building activities that have had a tremendous impact within the ocean sciences education community.

The ocean defines and dominates nearly everything about our planet. It seems so obvious why understanding and protecting the ocean is so critical to the future health of our planet. Climate change, ocean acidification, extinction, hurricanes, tsunamis dominate the news. And environmental concerns aside, the ocean provides over $43 billion per year to the economy in California alone.

And yet, when the National Science Education Standards were published in 1996, ocean scientists and ocean educators were dismayed that the National Standards contain almost no mention of ocean topics. As a result, none of the states' science standards include much about the ocean, coasts, or watersheds. Consequently, understanding about ocean topics has been ignored in most K-12 classrooms for at least a generation. There were exceptions of course, but without a coherent framework of concepts and messages, these topics remained on the margins of teaching and learning about science. As marine educators, we frequently found ourselves complaining about the absence of ocean concepts in the curriculum, and we were just as frequently asked back, "Well, what about the ocean IS missing? What SHOULD be taught about the ocean." And of course, there was no consensus about what the answer should be. The absence of ocean sciences in schools resulted in a generation of Americans largely ignorant of the importance of the ocean. How could it be that in states like California, Florida and Hawaii, the ocean is not systematically incorporated into the curriculum? Marine education had become marginalized. When it was taught, it was often presented in a very local context: if you live in "coastal community," then of course you might teach a little about your local area, but this resulted in an idiosyncratic presentation of ocean concepts. So, there grew a perception that marine educators were neither on the cutting edge of scientific discovery nor on the cutting edge of innovation in pedagogy.

In 2002, the NSF Division of Ocean Sciences, with a small contribution from NOAA) invested about $3.5 million in the competitive establishment of a National Network of seven Centers for Ocean Sciences Education Excellence (COSEE). Each Center is comprised of a partnership between an ocean sciences research institution, a formal education institution and an informal education institution. The mission of COSEE is to "Spark and nurture collaborations among scientists and educators to advance ocean discovery and make known the vital role of the ocean in our lives." I am the Director of COSEE California, one of the first Centers to be established in the National COSEE Network, and now in its eighth year of continuous funding. I can personally attest to how these Centers coalesced and elevated the ocean sciences education community. Much of the authority of COSEE has come from the presence of scientists. Because COSEE arises from a science research directorate at NSF, and not from the Education and Human Resources Directorate, there is a perception that ocean scientists themselves now believe that education is so critical, they are willing to devote their own research dollars to the endeavor. In the early days of COSEE, the Center Directors began to talk about creating an "ocean literate society" by infusing more ocean sciences concepts into the mainstream K-12 science education standards. We quickly realized that we needed to define what it meant to be ocean literate, and what ideas about the ocean are so essential that every student should understand them by the end of high school.

In 2004, the newly established NOAA Office of Education, made a small but highly strategic investment, perhaps just tens of thousands of dollars, to convene a series of online and face-to-face meetings between leaders of COSEE, NOAA, National Geographic Society, National Marine Educators Association and the College of Exploration (a distance learning organization) for the purpose of defining Ocean Literacy and determining what ocean sciences concepts should be in mainstream K-12 science education standards. The result was the publication a year later of a small brochure entitled, "Ocean Literacy: The Essential Principles of Ocean Sciences K-12." The brochure defines Ocean Literacy in the following way:

"Ocean literacy is an understanding of the ocean's influence on you and your influence on the ocean.

"An ocean-literate person:

- understands the essential principles and fundamental concepts about the functioning of the ocean;
- can communicate about the ocean in a meaningful way; and
- is able to make informed and responsible decisions regarding the ocean and its resources"

The pamphlet further describes seven principles of Ocean Literacy or seven big ideas that everyone should understand by the end of high school:

1) Earth has one big ocean with many features.
2) The ocean and life in the ocean shape the features of Earth.
3) The ocean is a major influence on weather and climate.
4) The ocean makes Earth habitable.
5) The ocean supports a great diversity of life and ecosystems.
6) The ocean and humans are inextricably interconnected.
7) The ocean is mostly unexplored.

Each principle is elaborated by a handful of "fundamental concepts," 44 in all, that can be seen at http://www.oceanliteracy.net.

The Ocean Literacy Brochure quickly became a consensus document, a unifying rallying point among ocean scientists and ocean sciences educators. There have now been nine entire conferences in three countries devoted to discussing the Ocean Literacy principles. A new high school textbook has been developed; another high school course is in development; museum and aquarium exhibits (including the Smithsonian's new Sant Ocean Hall) have been designed; lecture series and web sites abound; several states have incorporated ocean concepts into their science or environmental education standards; and of course the Ocean Sciences Curriculum Sequences (described above) are underway. Most Requests for Proposals released by NOAA now require applicants to address the Ocean Literacy Principles as a criterion for funding; and the same is true for RFPs coming from NSF Geosciences Directorate. The Ocean Literacy Brochure has certainly changed the way we think about the importance of providing children with opportunities to learn about the ocean. The process was so successful at bringing together scientists and educators to think deeply about the most important concepts within a domain, that it has been replicated several times. Similar brochures have now been published describing Atmospheric Literacy (supported by NOAA), Climate Literacy (supported by NOAA) and Earth Science Literacy (supported by NSF). These efforts have greatly helped to clarify and prioritize the big ideas in domains of science that are rapidly growing in importance and prominence. I have no doubt that these consensus documents will greatly influence the content of the future "Common Core" science standards now under development.

While the Ocean Literacy principles describe what students should know by end of Grade 12, a new, much more elaborate guidance document is now in press, *The Ocean Literacy Scope & Sequence for Grades K-12*. The Scope & Sequence describes what students need to know about each principle in Grades K-2, 3-5, 6-8 and 9-12. The impact of this document has not yet been felt (publication will be in mid-February), but it will no doubt be significant. The NOAA Office of Education has stepped forward with funds for its publication as a "National Marine Educators Association Special Report on Ocean Literacy Featuring the Ocean Literacy Scope & Sequence K-12." I have attached with this testimony electronic copies of both the Ocean Literacy Brochure and the DRAFT NMEA Special Report on Ocean Literacy.

NOAA and NSF funding for ocean sciences education has been highly complementary, and together has brought coherence to a once fractured and marginalized domain of science education. The small amounts of funding provided have been leveraged by building on lessons learned more broadly in science education through much larger investments from NSF Education and Human Resources Directorate. From a personal perspective, I can certainly say that NOAA and NSF have greatly enhanced the efficacy of my work and of the work of many of my peers and colleagues across the country.

In conclusion, I would like to repeat my thanks to you, Mr. Chairman and members of the Committee, for your past and continuing support of science education. I believe there are few areas in our society more important than public understanding of science, technology, engineering and mathematics. Widespread understanding of these areas which leads our young people to be creative and thoughtful decision-makers, is a key to the future health and prosperity of our economy, environment and quality of life. I would like to encourage your continued support of the science education efforts within NOAA, NASA, NSF and our other great science agencies.