Students' Conceptual Understandings of Science After Participating in a High School Marine Science Course

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ABSTRACT

This study analyzes responses to a researcher-developed science assessment given to students before and after their participation in a high school marine science course. While a paired-sample t test revealed a significant improvement ($p < 0.001$, $t = 4.42$, $n = 399$) on the post-instruction science content assessment, achievement gains were small based on Cohen's measure of effect size ($d = .22$) and varied among the nine teachers' classes. Student performance significantly improved for all groups of questions, with small gains for questions on the flow of matter and energy and the properties of water and less than small gains for questions about Earth's geologic history and interactions between the ocean and atmosphere. The results, based on improvement of students in two teachers' classes, indicate that marine science can be used as a successful model for teaching integrated science if curricula and instructional activities, assessments, and teacher education programs are aligned to the National Science Education Standards (NSES).

INTRODUCTION

Scientific literacy, a term commonly used to describe the goal of science education, refers not only to a person's knowledge of science but also to his or her ability to use this knowledge in making socially responsible decisions. The National Science Education Standards (NSES) (National Research Council (NRC), 1996) and the Benchmarks for Science Literacy (Benchmarks) (American Association for the Advancement of Science (AAAS), 1993) define scientific literacy by identifying the science standards and benchmarks that students should learn throughout their K-12 education. High school students who take the traditional courses such as earth science, biology, chemistry, and physics courses are the most likely to learn the content outlined in the NSES and Benchmarks and become scientifically literate adults. However, the majority of U.S. students do not choose to complete this sequence of traditional science courses.
Integrating science curricula offers a potential solution, and marine science, in particular, can provide a means to address all of the national science standards in one course: Unifying Concepts and Processes in Science, Science as Inquiry, Physical Science, Life Science, Earth and Space Science, Science and Technology, and the History and Nature of Science. Although marine science courses have existed for decades and provide a valid integrated curriculum model, they have not received national recognition as a potential reform mechanism for science education. By measuring high school students' understanding of general science concepts before and after their participation in a marine science course, this study provides initial support for an integrated approach.

THE RATIONALE FOR AN INTEGRATED SCIENCE CURRICULUM

Three primary premises support the rationale for integrating high school science curricula. First, according to large-scale science assessments, the majority of U.S. students are not learning the national science standards and benchmarks. In 1995, students in 41 countries took the Third International Mathematics and Science Studies (TIMSS), the most globally competitive and broadly publicized test. The study's most significant finding revealed that U.S. children, by the eighth grade, had fallen behind children of other countries in terms of science literacy (Valverde & Schmidt, 1998) and by twelfth grade, not only performed below the international average, but also were among the lowest scorers (USDOE, 1998). The National Assessment of Educational Progress (NAEP) has monitored student achievement in the United States for over three decades. In 1996 and 2000, NAEP was administered to nationally representative samples of 4th-, 8th-, and 12th-grade students. The 1996 NAEP science results showed students performing more poorly in 12th grade than in 4th and 8th grades. In 2000, the average science scores for the 4th- and 8th-grade students were not significantly different from scores in 1996; however, 12th-grade students' scores were significantly lower in 2000.

Course selection patterns provide a second reason for integrating science courses. Despite states' trends to increase science requirements, student enrollment in the traditional science courses has not increased (BSCS, 2000). Over 95% of high school students take biology, and 54% take chemistry, but only 23% take physics (Council of Chief State School Officers (CCSSO), 2001). Only 50% of students take physical science and 53%, earth and space science (O'Sullivan, Weiss, & Askew, 1998.). It is unlikely that alternative courses, which are often even more specialized, are closely aligned with the majority of the national or state standards or improve students' understanding of fundamental concepts in the core sciences (BSCS, 2000).

Third, contemporary science is practiced very differently from traditional science. "Most problems do not fit into neat disciplinary niches…the most effective investigators [are] those who are able to combine the insights and techniques of two or more disciplines" (Gardner, 1999, p. 219). Hybrids of traditional fields have merged into integrated research fields such as biochemistry, biogeo-chemistry, and genetics engineering (Hurd, 1991). Today, 95% of research reports have multiple authors as compared to 5% at the beginning of the last century, and teams combine the talents of scientists from related fields of natural scientists with social scientists (Hurd, 1998).

Traditional, single-discipline science instruction simply can no longer keep pace with the demands of contemporary science. In 1903, the Committee of Ten (representatives of leading U.S. colleges and secondary schools appointed by the National Education

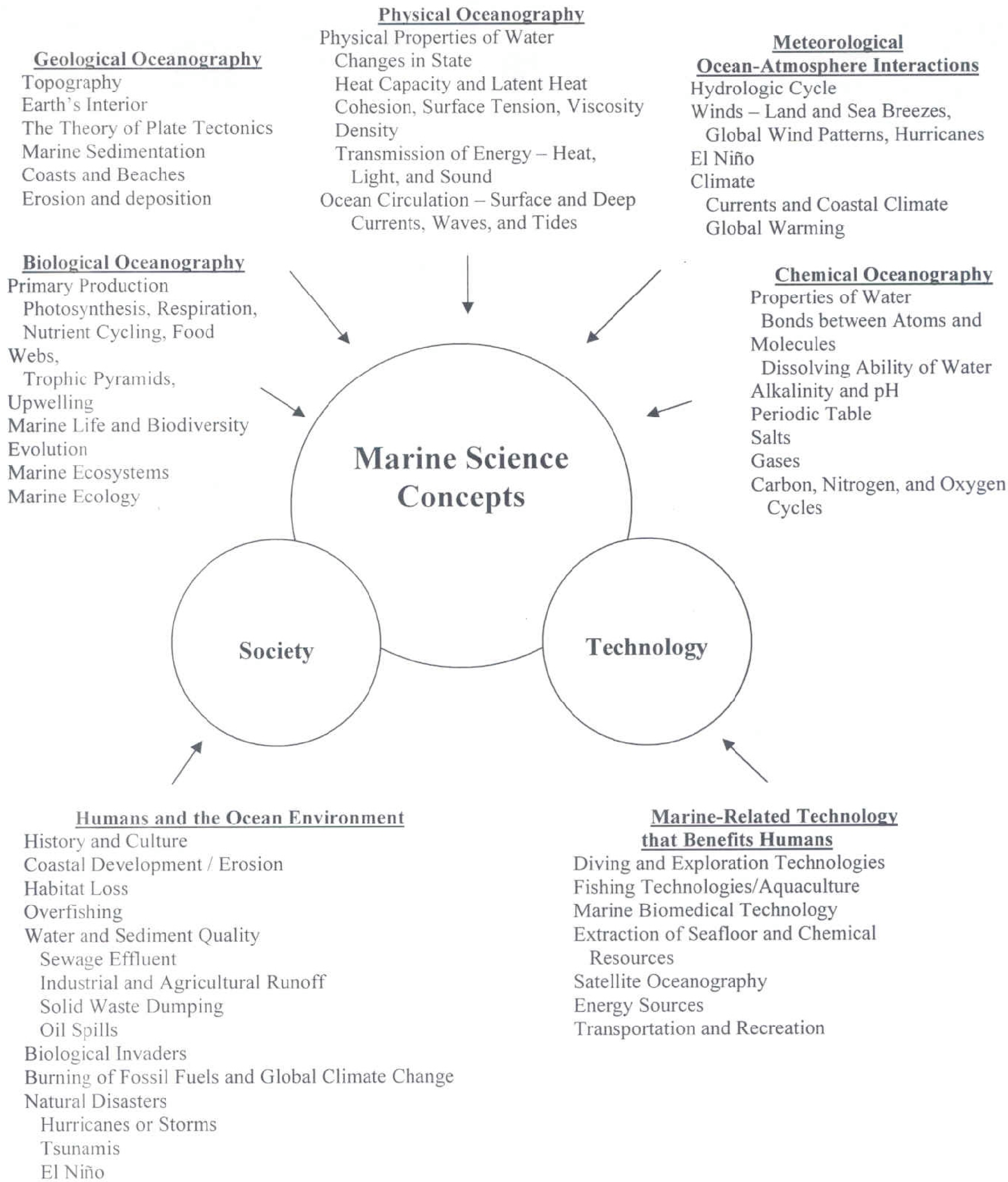

Figure 1. A Model for Integrating Science-, Technology-, and Society-related *National Science Education Standards* into Marine Science Curricula

Association) recommended students take four 1-year science courses: physical geography, chemistry, biology, and physics (Adams, 1971). This separation of disciplines or the "layer cake" approach is an artifact of the way science was studied and not a reflection of its true nature (McComas & Wang, 1998). Lopez (1996) concluded that students in an integrated science course were more completely exposed to the true nature of science than in a traditional, single-discipline science course. Advocates perceive integrated science instruction as an effective teaching method in a connected and context-rich manner that helps students apply science to their daily lives. This approach provides meaningful learning experiences by encouraging links between the sciences (McComas and Wang, 1998) and enables students to reach higher levels of scientific literacy (Horton, 1981). Hurd (1997) reiterates, "Most of the research in today's science is strategy oriented and cross-disciplinary; these are the first steps toward a modern science curriculum (p. 32)."

In conclusion, a contemporary science discipline like marine science naturally integrates the traditional sciences and serves as a unified instructional approach for many of the national science standards and benchmarks (Figure 1). This figure, developed by the author, shows how marine science can offer a common theme or context for scientific study throughout an entire academic year. For example, the study of complex ocean processes and systems (like the interaction between Earth's oceans and the atmosphere) provides a unique, coherent way to learn information from the fields of biology, chemistry, geology, physics, meteorology, and mathematics.

Although marine science is an inherently integrated discipline and a good candidate as a reform mechanism for science education at the high school level, significant educational research has not been conducted on marine science instruction and learning. Hundreds of articles can be found on marine science-related curriculum materials, programs, government reports, and career guides. A few articles even provide an analysis of the status of marine science education (e.g., Marine education: U.S.A.: An overview, National Oceanic and Atmospheric Administration (1998). Four studies were published on the marine science knowledge of students at various grade levels (Fortner & Teates, 1980; Fortner & Mayer, 1983; 1991; and Brody & Koch, 1990). These studies focused on students' understanding of specific marine science concepts but not on general science concepts.

This study, unlike prior ones, was conducted after the NSES and Benchmarks (which outline the science concepts that students should master in different grade levels) were published. These documents served as a framework for the study's design and investigation of high school students' understanding of general science concepts both before and after taking a yearlong marine science course.

METHODS

Research Context and Participants - Nine public high school teachers and their students located in seven different Florida counties participated in the study. Purposeful sampling was used in selecting the study's teachers and schools to represent a diverse range of teacher backgrounds and student populations, thus increasing the ability to generalize the findings. According to Florida's school grading system whereby schools are assigned an "A, B, C, D, or F," all of the schools were rated as "C" schools, except one, which was rated "D." This grade is based mainly on students' scores on statewide math and language arts tests.

The teachers' experience ranged from one year to thirty years, with fifteen years as the average. All teachers had undergraduate degrees in biology-related fields (two in marine biology), and two had master's degrees in science education (one was currently pursuing a Ph.D. in this area).

Of the 399 high school students participating in the study, approximately 37% were minorities, 75% were in the 11th or 12th grade, and the rest were in the 9th or 10th grade or did not respond. All of the schools counted marine science as a science credit for graduation. However, students' backgrounds in science prior to taking marine science varied, with 75% having had a course in biology, 51% in earth science, 43% in physical science, 31% in chemistry, 22% in Integrated Science I, 19% in Integrated Science II; and 8% in physics.

Curriculum and Instruction - In 1999, Florida combined existing marine science and marine biology semester-long a second year of marine science (Marine Science II). The Florida Department of Education's course descriptions for Marine Science I and II describe the two-year sequence as "an ongoing integrated study of all aspects of the marine environment." The course description for Marine Science I (http://www.firn.edu /doe/curriculum/crscode.crshome.htm) is the focus of this study. Table 1 provides a summary of the text(s), science content, and instructional practices used by each teacher in his or her classes. The table also shows the students' mean percentage gain from the pre to post assessment for each teacher.

Instrument - Science Assessment in Literacy (SAIL) is a multiple-choice assessment of students' knowledge of physical science, life science, earth and space science, science as inquiry, science in personal and social perspectives, the history and nature of science, and unifying concepts and processes. The assessment instrument was developed for this study to assess students' knowledge of science at the beginning and end of their participation in a marine science course. (See Lambert, 2001 for the complete instrument.) The SAIL instrument is based on the content standards outlined in the NSES and Benchmarks, the New York Regents Examination, and a survey by Laugksch and Spargo (1996). Over 90% of the 80 questions are related to specific standards and benchmarks: 21 questions on matter and energy, chemical reactions, and motions and forces; 26 questions on matter, energy, and organization in living systems; diversity of life; biological evolution; and interdependence of life; and 26 questions on Earth, the processes that shape Earth, and Earth in the solar system. Finally, seven questions relate to the NSES content standards for science as inquiry, science in personal and social perspectives, the history and nature of science, and unifying concepts and processes. For a detailed description of its development, validation, and determination of reliability, see Lambert (2001).

Data Collection and Analysis - To examine the change in students' understanding of science, teachers administered the SAIL assessment to their students at the beginning and end of their marine science course with students allotted 45 to 60 minutes to complete it each time. The scores on SAIL were analyzed using a paired-sample t test to compare the mean for the percentage of questions that students answered correctly on the pre- and posttest. Cohen's d was calculated to determine the effect size, which is a way of quantifying the difference between two groups. Effect size may be used to determine the magnitude, importance, or practicality of a difference or relationship (McMillan, 2004).

Interviews were conducted with small groups of two or three students within the same marine science class as they worked through the post-SAIL assessment. A total of 13 students out of 399 volunteered. Students read the questions and discussed the possible responses with each other, but each student individually marked his or her answer sheet. Analyses of transcripts of these sessions provided insight into students' understanding of science concepts after participating in a marine science course.

RESULTS

SAIL results were analyzed by comparing pre and post means for the percentage of the 80 questions that

Teacher	Text	Science Content (% of time)	Instructional Practices	Gain from Pre to Post
1 2	Sumich, 1992. *Introduction to the Biology of Marine Life* Duxbury and Duxbury, 1994. *An Introduction to the World's Oceans*	Biological 50 Chemical 17 Geological 17 Physical 17	Guided lectures with notes and questions, Laboratories, and Videos with questions <u>Other student activities:</u> Students summarize current events, e.g. red tide, ciguatera. *(These two teachers taught at the same school and shared instructional activities.)*	-1.8 T1 0.4 T2
3a 3b	No textbook issued to Integrated Science III students Garrison, 1993. *Oceanography: An Invitation to Marine Science* issued to dual enrollment students, but not used in instruction	Biological 13 Chemical 25 Geological 25 Physical 25 Other 12	"Interactive" lectures, Demonstrations, Laboratories, Projects, Field trips, Videos Water Planet videodisc, and Speakers <u>Other student activities:</u> Debates on local issues, Several science competitions, Seafood festival, Interdisciplinary projects, Construction of marine habitat models, sampling devices, and games	16.9*** 6.7
4	Gross, 1990. *Oceanography: A View of the Earth*	Biological 50 Chemical 17 Geological 17 Physical 17	Lectures, Laboratories, Power Point presentations, Water Planet videodisc, Internet projects, Speakers from local community, and Field trips <u>Other student activities:</u> Several dissections, Mangrove planting project, Research on careers, Writing/illustrating children's books.	-2.8
5a 5b	Sumich, 1992. *Introduction to the Biology of Marine Life* Developed own curriculum	Biological 50 Chemical 17 Geological 17 Physical 17	Lecture, Laboratories, Videos, Field trips <u>Other student activities:</u> Artificial reef project, SCUBA lessons	3.4 -5.8*
6	No textbook issued to students	Biological 25 Chemical 25 Geological 25 Physical 25	Lecture, Laboratories, Videos, Field trips, and Speakers from local community <u>Other student activities:</u> Integrated units	9.0***
7	Castro & Huber, 2000. *Marine Biology*	Biological 55 Chemical 15 Geological 15 Physical 15	Lectures, Discussions, Laboratories, Videos, HBOI Scientists' lectures, Field trips, Collaborative group projects, and Research projects <u>Other student activities:</u> Research cruise, Retreat for team building to plan cruise, Field laboratories	1.6
8	Thurman, 1984. *Marine Biology* for abiotic concepts Castro & Huber, 1997. *Marine Biology*	Biological 55 Chemical 15 Geological 15 Physical 15	Lectures, Laboratories, and Videos	1.7
9	Sumich, 1992. *Introduction to the Biology of Marine Life* Classroom set of: Pottenger et al., 1990. *The Hawaii Marine Science Studies The Fluid Earth* and *The Living Ocean*	Biological 50 Chemical 17 Geological 17 Physical 17	Lectures, Laboratories, Videos, and Field trips <u>Other student activities:</u> Students volunteer on the Cape Florida Restoration project each month, Students participate in National Ocean Science Bowl	0.4

Table 1. Marine science curricula and instructional practices and student achievement on SAIL science assessment. * statistically significant at $p < .001$; **, $p < .01$; and *, $p < .05$ $d > .20$ is "small effect size; $d > .50$, "medium"; and $d > .80$, "large." Pearson Product Moment Correlation between pre- and post-SAIL Assessments = .671 ($n = 399$). Group 3a includes Integrated Science III (marine science) students, and Group 3b includes dual enrollment oceanography students for Teacher 3. Both courses were taught with same curriculum and instructional practices. Teacher 5 taught year-long marine science courses during the fall (5a) and the spring (5b) on an accelerated schedule (i.e. Students take 4 courses in fall and 4 in spring).**

students answered correctly. A paired-sample t test showed a significant mean score improvement from 39.5% correct (SD = 16.8) on the pre-SAIL to 42.9% correct (SD = 19.7) on the post-SAIL ($p < .001$, $n = 399$). Cohen's d was .22, indicating a small effect size. A significant improvement in SAIL scores indicates that students' knowledge of general science increased during their marine science course; however, the average improvement was small with students correctly answering an average of only three to four more questions on the post-SAIL.

Significance of improvement on SAIL varied across the high school teachers' classes (Table 1). Mean scores of seven of the nine teachers' classes increased, but only two of these teachers' classes (Teacher 3 and 6) improved significantly by correctly answering an additional 17.0%

Themes and Concepts	Pre-Mean (%) Correct, SD	Post-Mean (%) Correct, SD	Gain (%)	Correlation	t value	Cohen's d (effect size)
Cellular Energy	35.5 (20.6)	38.9 (24.2)	3.4**	.222	3.09	.15
Interdepen-dence of Life	39.0 (25.0)	45.4 (29.9)	6.4**	.409	4.24	.21
Carbon Cycle and Atmospheric Gases	39.6 (31.9)	45.2 (30.5)	5.6**	.349	3.16	.16
Diversity of Life	39.6 (25.0)	39.9 (25.8)	0.3	.315	0.24	.01
Flow of Matter and Energy	38.0 (18.2)	42.2 (21.4)	4.4***	.519	4.30	.22
Geologic History	47.9 (26.4)	49.9 (26.5)	2.0	.478	1.50	.08
Plate Tectonics	37.6 (29.6)	41.9 (31.9)	4.3*	.327	2.41	.12
Earth's Changing Crust	50.9 (41.6)	52.5 (41.1)	1.6	.352	0.69	.03
Theory of Plate Tectonics	45.4 (24.4)	48.0 (25.9)	2.6*	.530	2.15	.12
Anomalous Properties of Water	44.9 (30.0)	48.7 (32.0)	3.9*	.401	2.21	.11
Ionic Components of Seawater	42.7 (37.3)	47.1 (40.7)	4.4*	.470	2.18	.11
Acids and Bases	28.6 (32.1)	31.5 (34.6)	2.9	.065	1.26	.06
Density	31.8 (28.3)	38.3 (30.7)	7.5***	.298	3.72	.19
Water Cycle	28.2 (26.3)	31.2 (28.3)	3.0*	.379	2.02	.10
Properties of Water	35.1 (17.4)	39.4 (20.7)	4.3***	.591	4.80	.24
Global Energy	30.8 (24.9)	31.6 (26.6)	0.8	.411	0.63	.03
Electromag-netic Spectrum	42.3 (24.2)	43.3 (24.5)	1.0	.366	0.73	.04
Pressure, Winds, and Currents	31.7 (33.2)	35.5 (36.5)	3.8	.221	1.72	.09
Climate	43.9 (35.5)	50.4 (34.6)	6.5**	.227	2.99	.15
Seasons	35.3 (29.2)	38.8 (32.1)	3.5	.287	1.91	.10
Ocean and the Atmospher Interactions	26.0 (17.1)	38.8 (19.1)	2.8**	.549	3.20	.16

Table 2. Summary of student performance for themes. d > .20 is "small effect size; d > .50, "medium"; and d > .80, "large."

and 9.0% of the 80 questions on the post-SAIL. Cohen's d was 1.27 and .57, indicating a large and a medium effect size, respectively. These two teachers taught marine science using an integrated approach with approximately equal time devoted to geological, chemical, physical, and biological topics.

Students' responses to individual questions were analyzed using four frameworks of interrelated concepts that show how science concepts are connected in marine science and shown in Table 2.

Table 3 shows a sample of the SAIL questions, the percentage of students who selected the correct response and distracter response on the pre- and post-SAIL, and the significance of the change in the percentage of students choosing the correct response (for the complete SAIL analysis, see Lambert, 2001). These questions were selected to show how typical concepts for each of the four frameworks were assessed.

DISCUSSION OF FINDINGS

Based upon the overall analysis of 399 Florida high school students' response patterns on the before-and-after science assessment (SAIL), certain initial evidence, based on students' improvement in performance in Teacher 3's and Teacher 6's classes, supports using an integrated marine science curriculum to increase students' knowledge of science. Although an

Questions	% of Students who Chose the Correct Response on Pre- and Post-SAIL (Significance) % of Students who Chose the Distractor on Pre- and Post-SAIL
Flow of Matter and Energy	
Which equation illustrates the process of photosynthesis carried out within the leaf?	• water + carbon dioxide -> water + glucose + oxygen (40%, 40%) • glucose + carbon dioxide -> water + oxygen (23%, 23%)
Phytoplankton (microscopic plant-like organisms) play an important role in balancing Earth's climate by _____.	• Using carbon dioxide and producing oxygen (48%, 53%) • Using nitrogen and producing carbon dioxide (14%, 16%)
Which of the following groups of organisms would be more closely related?	• Human, cat, dog, manatee (40%, 46%) • Fish, jellyfish, starfish, crayfish (35%, 25%)
Theory of Plate Tectonics	
The most accurate estimation of the age of the Earth is based on _____.	• The decay rate of radioactive isotopes in rocks (42%, 38%) • The thickness of sediments in the ocean basins (41%, 41%)
The theory of continental drift was widely criticized in the first half of the twentieth century. What later evidence discovered using new technologies after World War II supported Wegener's original theory of continental drift?	• Patterns of magnetism in the ocean's crust (39%, 41%) • Upwelling along coasts of continents (19%, 22%)
Where do the vast majority of earthquakes occur?	• Near the edges of plates (49%, 50%) • In the middle of crustal plates (20%, 17%)
Properties of Water	
Water is referred to as "the universal solvent." The dissolving ability of water is related to its _____.	• Ability to attract both positive and negative ions (29%, 37% - Significant Increase) • Ability to exist in solid, liquid and vapor phases (51%, 44%)
What determines how atoms of elements in the same group or family of the Periodic Table will react with atoms of different elements?	• Outermost electrons (42%, 47%) • Energy levels (28%, 22%)
If a sample of seawater has a pH of 8, it means _____.	• OH^- ions outnumber H+ ions, and the seawater is alkaline or basic (38%, 38%) • H+ ions outnumber OH^- ions, and the seawater is acidic (27%, 32%)
Thermohaline circulation accounts for deep, slow currents in the major ocean basins that flow and mix seawater all over the globe. Based on your knowledge of buoyant and gravitational force, what characteristics of water would a sinking water mass have?	• Cold and saline (40%, 41%) • Cold and fresh (24%, 20%)
Under which set of atmospheric conditions does water usually evaporate at the fastest rate?	• Warm temperatures, high winds, and low humidity (30%, 31%) • Warm temperatures, calm winds, and high humidity (54%, 49%)
Ocean and Atmosphere Interactions	
The energy from the sun does all of the following EXCEPT _____.	• Provides a source of heat for the Earth's interior (33%, 35%) • Drives convection currents in the atmosphere and oceans (26%, 30%)
If water only absorbed light and did not scatter it, what color would the sea appear when viewed from above?	• Black (43%, 39%) • White (29%, 26%)
Recent studies of gases in the atmosphere show that the amount of carbon dioxide has increased steadily over the past hundred years. All of the following release carbon dioxide into the atmosphere EXCEPT _____.	• Photosynthesis by green plants on land and algae in water (37%, 44% - Significant Increase) • Burning of fossil fuels and forest fires (19%, 19%)
The changing seasons on Earth are caused by _____.	• The tilt of the Earth's spin axis as it orbits the sun (55%, 58%) • Variations in the distance of the Earth to the sun (14%, 14%)

Table 3. Summary of student performance on a sample of SAIL questions.

analysis of responses to individual questions was equivocal, at best, an analysis of responses to questions grouped by theme or subject showed significant student improvement (Table 2). The discussion below identifies factors influencing student responses, outlines recommendations to improve teaching and learning, and examines the implications with respect to scientific literacy.

Factors Influencing Students' Responses - First, it appears that several teachers either failed to incorporate important concepts related to diversity and the evolution of life, the theory of plate tectonics, density, acid/base reactions, and interactions between the ocean and atmosphere into their curricula or failed to adequately teach them. For example, on the post-SAIL only about 50% of the students (no change from the pre-SAIL) chose the correct response of "human, cat, dog, and manatee" as the group of individuals being the most closely related, and 25% still chose the wrong answer of "fish, jellyfish, starfish, and crayfish." Even though the NRC standards clearly state that students often rely on "everyday" classifications (such as viewing a jellyfish as a fish because the names includes the word "fish") for identification, the teachers failed to help the majority of students learn how to classify animal species. Students also did not seem to gain a real understanding of the differences between invertebrates, chordates, and vertebrates. The majority failed to recognize that only the shift from a notochord to a backbone (and not the shift from filter feeding to jaws and gills to lungs) was pivotal in the evolution of all vertebrates, indicating that students may not have known that fish are vertebrates.

Another topic not adequately covered in the curriculum was the theory of plate tectonics, which provides a modern explanation of the movement of Earth's crust and combines the theories of continental drift and seafloor spreading. Students seemed to have a better understanding of the evidence for continental drift; however, they lacked a clear understanding of the processes of seafloor spreading and the relationship between plate tectonics, earthquakes, and volcanoes.

And while students' scores improved on more than half of the questions relating to the properties of water, less than 40% of the students could identify a substance as an acid or a base when given the pH value. Less than half of the students appeared to understand density after taking the course. (According to the AAAS benchmarks, students should know that the action of gravitational force on regions of different densities causes them to rise and fall and that such circulation, influenced by the rotation of Earth, produces winds and ocean currents.)

Second, students had difficulty learning concepts related to individual processes when these were taught out of context. However, when students learned about these processes within a systems-based or ocean context, their comprehension improved. For example, students still appeared not to recognize isolated equations for photosynthesis and respiration even after taking biology and marine science courses. This finding is consistent with Anderson and Sheldon's (1990) study of American college non-biology majors' ideas about respiration. Students in their study did not link food, oxygen, carbon dioxide, and energy in any way that indicated they understood respiration. Students in the present study, however, performed significantly better when questioned about the possible reasons for an increase in atmospheric carbon dioxide. This indicates that they had a better understanding of how these processes affect the balance of gases in the atmosphere.

Another example of improved student comprehension at the systems level is students' understanding of the flow of energy. Most students appeared to comprehend the flow of energy through ecosystems rather than at the cellular level. Clearly, the students learned best when the subject matter was taught within the overall context of an ecosystem.

Third, students had several basic misconceptions. One misconception was related to the students' experience of living in Florida's subtropical climate, thereby possibly confusing their understanding of the water cycle. When students were shown a water cycle diagram and asked which environmental factor causes clouds to form, they were no more likely to choose the correct response in the post-SAIL than in the pre-SAIL test. Students said that thunderstorms and clouds form on warm, humid summer days and that warm land must therefore be the reason that clouds form. Even though the water cycle is taught in elementary school, this study's results indicate that most students still do not understand its underlying processes by the time they reach high school.

Another misconception concerned the interaction between light waves and matter. Based on SAIL results, students seemed to understand the components of light waves and refraction, but less than 30% of the students chose the correct order of electromagnetic waves (from the longest wavelength to the shortest). Students also appeared not to understand that reflected wavelengths give objects their color. In other studies, middle school students in some situations also rejected the idea that ordinary objects reflect light (Guesne, 1985; Ramadas & Driver, 1989).

The most common explanation for the cause of seasonal changes is variations in the distance of Earth to the sun (Baxter, 1989). In the current study, 58% of the students chose the correct verbal explanation for seasonal changes, "the tilt of the Earth as it revolves around the sun," and only 14% chose variations in the distance of the Earth to the sun (See Table 2 & 3). However, only one-third of the students were able to correctly interpret a diagram demonstrating this concept.

Finally, in the interviews, students reported having difficulty in understanding common scientific vocabulary terms that are necessary for learning fundamental scientific concepts. Examples of these vocabulary terms include asexual reproduction, convection, pressure, radiation, runoff, solvent, weathering, and erosion. Students of Teacher 9, who used the University of Hawaii's The Fluid Earth (Klemm, Pottenger, Speitel, Reed, and Coopersmith, 1990) and The Living Ocean (Klemm, Pottenger, Speitel, Reed, and Porter, 1995) textbooks, said that the inclusion of Latin prefix and suffix definitions helped them to learn and remember names of organisms and processes. While many of her students were English Language Learners (ELL's) and did not make significant improvement on the assessment, the students' comments suggest that textbook or curriculum materials, which effectively review basic vocabulary and concepts, may be a factor that could positively influence their ability to learn science.

Implications and Recommendations To Improve Marine Science Instruction and Learning - Given the paucity of research on marine science education and the increase in the number of Florida high school students enrolled in marine science courses from 11,700 in 1998 to 31,947 in 2003-4, this study's initial description and analysis of students' post-course understanding of science concepts provide important data. These data suggest that content deficiencies in the current marine science curriculum exist. Although the national science standards and benchmarks and Florida's Sunshine State Standards (which define the intended science curriculum for grades 9 through 12) were available to the teachers participating in this study, marine science standards are not explicitly defined in any of these documents. Moreover, Florida's course descriptions for Marine Science I and II do not give teachers the specific guidance they need to plan their courses.

Textbooks remain the leading source of resource materials for teachers, based on a survey of National Marine Educators Association members (Walker, Walters, and Allen, 2003). Major textbook companies for formal K-12 education still do not publish high school-level marine science textbooks, and most of the marine science textbooks commercially available are at a university reading level and do not include inquiry-based activities as called for by the NSES. Six of the nine teachers (Teachers 1, 2, 5, 7, 8, and 9) used university-level marine biology textbooks, while three (Teachers 1,2, and 4) used university-level oceanography textbooks. Six teachers (Teachers 1, 2, 4, 5, 8, and 9) used textbooks more than 7 years old. Two teachers (Teachers 3 and 6) did not use textbooks and had students take notes based on class lectures. Interestingly, these two teachers taught marine science with equal time devoted to geological, chemical, physical, and biological topics, and students of these two teachers improved the most on the SAIL. This finding may indicate that the textbooks issued were not adequate and/or that the two teachers who did not issue textbooks were more knowledgeable and better able to integrate the national standards and benchmarks into their marine science curriculum and instruction.

One solution would, therefore, be to review the national standards and benchmarks in order to cross-reference concepts and processes that apply both to marine science and traditional science disciplines. The next step would be to align curriculum and instructional practices (enacted curriculum) with the identified national standards and benchmarks (intended curriculum). It may therefore be necessary to develop new curriculum and instructional materials that align to the national standards and benchmarks. Once this occurs, teachers will have a roadmap showing them how to integrate basic sciences into their marine studies. This alignment also would give researchers a set of standards by which to evaluate students' learning (learned curriculum) resulting from participation in an integrated marine science course.

The findings of this study also suggest that students learn more when concepts are taught using the context of a system (like the ocean) as a holistic framework. However, in order for teachers to use an integrated approach, they must first master content not only in marine science, but also in biology, chemistry, geology, physics, and meteorology. Teachers' knowledge of the subject matter along with their understanding of how students learn and effective teaching methods have been shown as being key to effective teaching (Darling-Hammond, 1996). Research also has shown a positive relationship between the amount of science coursework taken by teachers and their students' learning (Shavelson, McDonnell, Oakes, and Carey, 1989). While all of the teachers in this study had an undergraduate degree and teaching experience predominately in the field of biology, only one teacher (Teacher 3) had a bachelor's degree in marine biology, a master's degree in science education (with a minor in geophysics), and had begun coursework in a science education doctoral program (Table 1). With his background and experience teaching all of the basic science courses, this teacher was uniquely suited to utilizing an integrated approach, and his students' knowledge of science increased the most, as measured by the SAIL. However, this type of integrated training must become the norm and not the exception. Teacher preparation and professional development programs must address this need for an integrated approach to the teaching and learning of science, as two-thirds of states in the United States have a broad-field secondary science certification that covers teaching in biology, chemistry, physics, and other science subjects (CCSSO, 2001).

Data from this study also highlight the problem of persistent student misconceptions and inadequate vocabulary skills. Hence, the results indicate that teachers must present content at an appropriate level, carefully explaining terms and concepts, and providing opportunities for students to practice and apply these terms and concepts. Unlike students in an upper-level science class, students in a marine science class come with a wide range of science experiences, mostly due to the fact that the prerequisites for marine science courses vary among schools and students have taken a variety of science courses. Hence, a valid preassessment can help teachers identify students' prior knowledge. Teachers may then have to review or teach several of the NRC standards and AAAS benchmarks at the level the students can understand. The preassessment tool also may help teachers choose curriculum and instructional resources that will meet the needs of students, again indicating the necessity of standards-based resources.

In summary, if students are expected to learn the national science standards and benchmarks by the time they complete high school, course-taking patterns and science curriculum and instruction must be adjusted. Further research documenting the effectiveness of using an integrated approach, such as marine science, for science instruction will be required. In this study, teachers' curricula were not aligned with the research-based science assessment (which was constructed and aligned to the national science standards and benchmarks), and even though the reliability coefficient of SAIL was high, the instrument still had limitations. The large sample size necessitated a multiple-choice format that should be revised to include two-tier multiple-choice items, in which one tier involves a content response while the second involves a reasoning response (see Treagust, 1995). More focus group discussions of students' conceptual understandings should also be incorporated in future research.

The success of an integrated approach to marine science will depend upon the development of measurable and appropriate standards-based marine science curriculum and instruction. School systems also must provide professional development opportunities to help teachers gain deeper content knowledge and learn effective instructional practices, including methods to assess students' prior knowledge. Once these steps are in place, future research can center on more in-depth case studies to investigate the outcomes of standards-based marine science curricula and instructional practices on students' understanding of science concepts.

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