ARIES: Astronomy-Based Physical Science

Physical and Earth/Space Science

ARIES, developed at the Harvard-Smithsonian Center for Astrophysics (CfA), with funding from the National Science Foundation (grants MDR 91-54113 and ESI 95-53845) and with additional support from Harvard University and the Smithsonian Institution.

ARIES is a modular, astronomy-based physical science curriculum for students in grades 3-8. It provides classroom teachers with effective pedagogical strategies to help students construct new understandings of the natural world. Over a ten-year period beginning in 1991, scientists and science educators at the Science Education Department (SED) of the CfA developed explorations and materials for eight self-contained modules. Each module includes intercurricular extensions. A companion project, Project SEDNet (NSF grants TE 9819459 and ES 0101958), in collaboration with more than 25 Challenger Learning Centers (CLCs), provides professional development in regions across the nation.

ALIGNMENT WITH NATIONAL AND STATE STANDARDS

ARIES is aligned with national and state standards. In particular, there is a match between the ARIES process and the attributes of science education called for in the *National Science Education Standards.*[1] ARIES has all the features of discovery-based learning that the Standards require: observation, student generated questions, prior-knowledge activation, prediction, hypothesis formation, data collection, graphic representation of data, assessments, and curricular connections. ARIES builds understanding of science vocabulary and the scientific method as students write in science journals through each module. The curriculum is based on research into misconceptions and built around a pedagogy that requires both students and teachers to develop new models of the natural world. Focused on a manageable number of major concepts, ARIES is designed to make science accessible to children through observation and discovery. For teachers, the "stand and deliver" process is replaced by the "coach approach."

RESEARCH-BASED, RESEARCH-VALIDATED

ARIES is based on current research and validated by extensive classroom field-testing. It is informed by research conducted at the SED and elsewhere into the effects of prior ideas on student learning and the implications of those effects for classroom pedagogy. ARIES is also validated by extensive formative and summative evaluation, including comparison testing with students of all abilities in a wide range of settings.

Charlesbridge

Charlesbridge Publishing,
85 Main Street, Watertown, MA 02472
800-225-3214 phone 800-926-5775 fax
www.charlesbridge.com/school/aries

Research Basis

Three interrelated issues shape the ARIES curriculum:

1. **Research into children's misconceptions,**
2. **Research into how people learn, and**
3. **Science content that is accurate, focuses on major concepts or themes in astronomy, physical science, and space science, and accessible to students and teachers.**

Since 1985, the SED has been a national leader in developing innovative, research-based science curricula framed around these three issues.[2] The department has placed a special emphasis on projects for elementary and secondary students, all with links to age-appropriate mathematics. Much of the department's success is based on the way it brings together educators and scientists to work on projects combining curriculum development, learning theory, teacher enhancement, and technology.

1. Student Misconceptions and Learning

For nearly two decades, the SED has been documenting and studying the persistence of students' scientific misconceptions, prior ideas, or alternative theories in spite of some of the very best science teaching. The department's research on how misconceptions block learning was documented originally in its Science Media Group's award-winning videotape, *A Private Universe.* More recently the *Minds of Our Own* series shown on PBS reinforced that documentation, showing how students' prior ideas remain impediments to deeper understanding of the physical or natural world even in the face of compelling evidence or observations negating these ideas. As a result, the SED has designed its curricula around explorations and classroom teaching strategies that help students reexamine their personal models of the natural world. It is only when students have sufficiently collected and analyzed their own new evidence that they are open to reassessing and changing their model of the natural world.

Understanding of physical science and space science phenomena is often counterintuitive. SED researchers have examined the ideas of K-16 students involving concepts such as moon phases, seasons, Earth's motions, size, scale, acceleration, energy, waves, light, color, and more. Many students, even those in higher education, continue to hold on to models that are inconsistent with those of scientists, no matter the number of science courses taken. As a result, most science educators now recognize the need for students to build their own understandings of the natural world rather than to learn about someone else's models.

2. Constructivism: How People Learn

The learning model used by the SED, and imbedded in ARIES, is based on a pedagogy that helps children construct or reconstruct, or change conceptually, their understanding of the natural world. This model, or philosophy, is often broadly labeled *constructivism*. Constructivism focuses on ways to help children build their own personal views of everyday phenomena based on evidence from their observations of nature.[3] It holds that learning is meaningful and useful when it helps learners make sense of the world around them.

A constructivist approach to learning has grown out of cognitive research. Although this approach predates Piaget, his research gave perhaps the greatest impetus to the widespread studies of student misconceptions carried out over the last forty years.[4] Broadly stated, this approach holds that knowledge is constructed by learners; it is not something that can generally be given to students by a teacher. Students come to class with ideas about the world that have been constructed from their everyday experiences, yet many of these ideas contrast sharply with accepted science. In spite of years of formal education, students hold strongly to their alternative views. The pedagogy of ARIES helps students begin to question these intuitive, everyday views or models. Where the models are not supported by their observations, it then becomes necessary for students to rethink their ideas.

3. Accuracy and Accessibility of the Science in ARIES

The developers of ARIES created a curriculum that is both scientifically accurate and readily accessible to students and teachers in any setting. Irwin Shapiro, principal investigator of ARIES, read and edited each module for science accuracy. Dr. Shapiro is Director of the Center for Astrophysics, a member of the National Academy of Sciences, and University Professor at Harvard University. Additionally, the NSF sent the first three modules to six other scientists for review. All six reviewers rated the ARIES modules as exemplary in science content (no errors were identified) and in accessibility for teachers and students.

The developers of ARIES understood that children need to build up a set of skills or intellectual tools that will help them look at the natural world in a new and meaningful way. As a start, the scope of the science curriculum needs to include examining or studying a few concepts from multiple perspectives, rather than trying to look at every concept. Further, the science lessons must be of interest to children and related to their everyday experiences. Learning science concepts and scientific method go hand in hand; the processes of science cannot be construed as entities unto themselves, but rather are to be used in understanding concepts more meaningfully. These twin pillars of learning are constructed as students write in the science journal of every module.

Research Validation

In 1996-97 the developers of ARIES conducted a comparison study of three modules in 31 elementary and middle-school classrooms.[5] The study involved approximately 750 students in 15 classrooms using ARIES materials and approximately 650 students in 16 control classrooms.[6] Students in the control classrooms covered the same major concepts as the ARIES students.[7] All students in the two groups were tested on 17 different items, both before and after classroom instruction. All the items were open-ended, paper-and-pencil questions. The change between the pre-teaching and post-teaching scores of the ARIES and control class students was compared and analyzed. The overall data show that ARIES students both a) significantly increased their conceptual understanding of the materials taught, and b) significantly outperformed students in control classes where the same topics were taught without ARIES.

Prior to the comparison testing, evaluators assessed more than 1,550 grade 3-7 students using ARIES materials to measure the impact of the project materials on student learning. Classroom teachers and science educators reviewed the items on these unit tests to assure that the questions could be understood by children in grades 3-7. For the comparison study, evaluators then constructed a "Sampler Test" for the control classes consisting of 17 items selected from the unit tests used in the ARIES classrooms. None of the items in the Sampler were module-specific. Evaluators used the following selection process. The classroom teachers in the control schools provided a curriculum guide detailing the scope and sequence of their science program. Where a curriculum guide did not exist, the control teachers were provided with a checklist of concepts or topics addressed in the ARIES modules.[8] The control teachers noted which of the concepts or topics in the curriculum guides or on the checklist they taught their students. Concerned for fairness, and in order to minimize bias, evaluators chose test items that involved concepts or topics which participating teachers planned to teach during the school year.[9] Using this process, only questions related directly to the concepts or topics taught in both the ARIES and control classrooms were selected.

The open-ended feature of the questions makes it possible for students to demonstrate both their answers and how they arrived at their answers. The same questions were used for the pre-teaching and post-teaching tests. A scoring rubric for each question was developed that permitted evaluators to assess the range of student understanding for each concept addressed. The scoring manual — comprised of the scoring rubrics for all of the questions — was then tested for inter-rater reliability. It was established at >0.90, which matches the inter-rater reliability established with the earlier summative evaluation. Both ARIES and control teachers returned completed tests to the evaluation office. Evaluators adhered to the scoring manual when scoring all the tests.

Two types of statistical tests were performed on the data. The first test involved only the ARIES classes. Here, to test the null hypothesis that there was no change from the pre-teaching to post-teaching tests, a paired comparison t-test was used. This t-test is used when subjects are tested twice and the difference from pre-test to post-test is the dependent variable. The result of the test is a ratio that is related to a level of significance. That level of significance is the probability that the difference could have occurred by chance. Most statisticians agree that a level of significance of 0.05 or less means that the difference between the scores is NOT likely due to chance, but to some intervention between the two testings — in other words, that the difference is statistically significant.

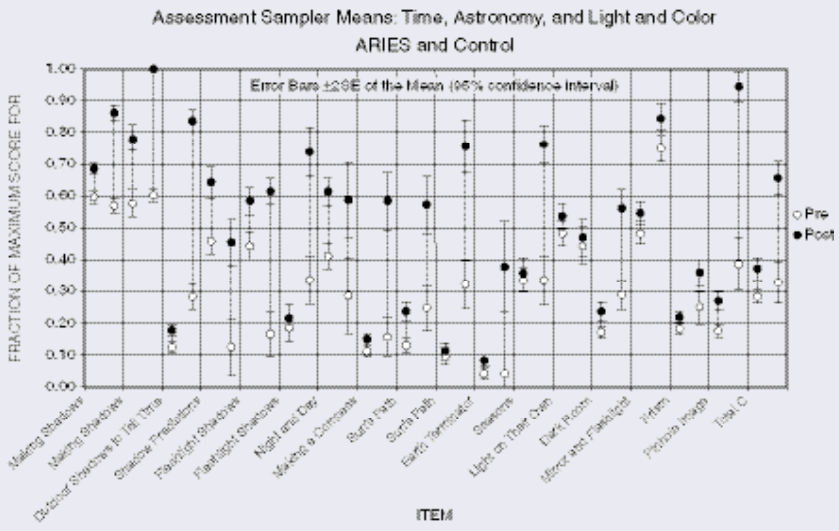
The second test involved both the ARIES classes and the control classes. Here, it was not possible to randomly assign children to one group or the other. The control populations were chosen to reflect a demographic distribution similar to the ARIES classes. However, in this study there were some differences on the pre-test scores between the ARIES classes and the control classes. When groups differ on a pre-test, it is difficult to attribute differences on a post-test to an intervention. Therefore it is necessary to perform a procedure that will make the two groups statistically equivalent. An adjustment or control must be made for differences that appear on the pre-test between the groups. The appropriate method in this case is analysis of covariance. Here, the dependent variable is either the gain score or the post-teaching score and the covariate is the pre-teaching score. The analysis is actually performed on the adjusted gain or post-teaching scores. The result of this test is an F statistic related to levels of significance. This test measures the difference between the two groups on either their gain scores or post-test scores. If the level of significance is below 0.001, the probability that the difference between the two groups is due to chance is less than one in a thousand. The Effect Size (ES) differences are dramatic on these tests. For the control group ES = 0.238 (SE = 0.049), and for ARIES classrooms the ES = 1.075 (SE = 0.128).

The accompanying table shows the raw pre-test and post-test means and gains for the two student populations (ARIES and control) for each of the items.[10] The table also includes the standard error means for each group's post-test scores and gains. The numbers of ARIES students and of control students vary. For ARIES groups, this variation reflects the fact that some teachers were unable to complete a full module. For the control groups, it reflects the fact that in some instances students were directed to skip the Sampler questions pertaining to topics not addressed during the year. The post-test scores for ARIES students are, statistically, significantly greater than the scores of the students in the control classrooms for 15 of 17 items.

Table – Comparative Results from the ARIES and Control Classrooms

	Item	No. of Students	Maximum Score	Pretest Mean	Posttest Mean	Gain	Significance
1A	ARIES	298	3	1.698	2.567	0.869	<0.001
	Control	506		1.792	2.055	0.263	
1B	ARIES	298	1	0.460	1.000	0.540	<0.001
	Control	506		0.573	0.781	0.208	
2	ARIES	298	3	0.862	2.510	1.648	<0.001
	Control	506		0.381	0.542	0.160	
3	ARIES	159	3	1.491	2.447	0.956	<0.001
	Control	506		0.927	1.275	0.348	
4	ARIES	159	2	1.189	1.805	0.616	<0.001
	Control	506		0.885	1.164	0.279	
5	ARIES	159	1	0.321	0.730	0.409	<0.001
	Control	506		0.182	0.215	0.034	
6	ARIES	68	1	0.294	0.588	0.294	.889
	Control	506		0.411	0.611	0.200	
7	ARIES	73	2	0.315	1.164	0.849	<0.001
	Control	506		0.217	0.298	0.081	
8	ARIES	73	2	0.493	1.151	0.658	<0.001
	Control	506		0.271	0.472	0.202	
9	ARIES	50	2	0.640	1.520	0.880	<0.001
	Control	506		0.196	0.223	0.028	
10	ARIES	50	1	0.040	0.380	0.340	<0.001
	Control	506		0.036	0.081	0.045	
11	ARIES	183	1	0.339	0.765	0.426	<0.001
	Control	454		0.335	0.355	0.020	
12	ARIES	183	7	3.120	3.284	0.164	0.113
	Control	454		3.368	3.729	0.361	
13	ARIES	183	2	0.585	1.120	0.536	<0.001
	Control	454		0.313	0.476	0.163	
14	ARIES	181	3	2.293	2.519	0.227	<0.001
	Control	454		1.454	1.623	0.170	
15	ARIES	114	2	0.491	0.728	0.237	<0.001
	Control	454		0.357	0.447	0.090	
16	ARIES	90	2	0.778	1.889	1.111	<0.001
	Control	454		0.328	0.540	0.211	

The accompanying graph compares the median pre-test and post-test scores (with error bars based on two standard errors) of the ARIES students to those in the control classrooms. These data show that, with very few exceptions, students working with ARIES materials significantly increased their understanding of the concepts taught. These data also show that ARIES students significantly outperformed students in control classes in which the same topics were taught, but without ARIES materials.



[1] National Science Education Standards. National Academy of Sciences: Washington D.C., (1995).

[2] To date, the SED has received funding for more than 25 projects. Support for the projects comes from the NSF, the Annenberg Foundation, NASA, Harvard University, and the Smithsonian Institution.

[3] Ausubel, D. *Educational Psychology: A Cognitive View,* Holt, Rinehart, and Winston: New York (1968). Driver, R. *The Pupil as Scientist?* The Open University Press: Milton Keynes, England (1983). "What Science is Learning About Learning Science," *The Journal of NIH Research,* Vol. 2 (May 1990). Kyle, W., et al. "Enhancing Prospective Teachers' Conceptions of Teaching and Science," *Journal of Science Teacher Education,* Vol. 1, No. 1 (Spring 1989). Roth, K.J. "Science Education: It's Not Enough to 'Do' or 'Relate,'" *The American Educator,* American Federation of Teachers: New York (Winter 1989); Novak, J. "How Do We Learn Our Lessons?" *The Science Teacher,* pp. 51-55 (March 1993). Novak, J., *Learning to Learn,* Cambridge University Press: New York (1983). Yager, R. "The Constructivist Learning Model," *The Science Teacher,* pp. 53-57 (September 1991).

[4] Piaget, J. *The Child's Conception of the World,* Harcourt Brace, New York, 1929. Posner, G. J., et al. "Accommodation of a Scientific Conception: Toward a Theory of Conceptual Change," *Science Education,* 1982, Vol. 66, No. 2, pp. 211-227. Novak, J. "A View on the Current Status of Ausubel's Assimilation Theory of Learning," *Paper to the American Educational Research Association,* San Francisco, April, 1992. Nussbaum, J. "Children's Conceptions of the Earth as a Cosmic Body: A Cross-Age Study," *Science Education,* 1979, Vol. 63, No. 1, pp. 83-93. Vosniadou, S. "Designing Curricula for Conceptual Restructuring," *Journal of Curriculum Studies,* 1991, Vol. 23, No. 3, pp. 219-237. Hawkins, D. "Messing About In Science," *The Informed Vision: Essays on Learning and Human Nature,* Agathon Press: New York (1974).

[5] *Exploring Time: Sundials, Water Clocks, and Pendulums; Exploring Light and Color: Filters, Lenses, and Cameras; and Exploring The Earth in Motion: Daylight, Sun, and Shadow Patterns.* The modules were field-tested in more than 100 schools nationwide from 1993-1998. Teachers can use a module for 14-18 weeks if science is done twice a week. Dr. Marcus Lieberman, president of Responsive Methodology of Albuquerque, New Mexico, with assistance from Annette Trenga, conducted the external evaluation.

[6] There were ARIES classrooms in urban, suburban, and rural settings. The control classrooms were in urban and suburban settings.

[7] The topics included the nature and cause of shadows and outdoor shadow patterns, the apparent daily motion of the Sun and its changing path across the sky from season to season, day and night and the changing hours of daylight and darkness from season to season, light and its role in vision, the scattering and reflection of light, color, and lenses and the refraction of light.

[8] The amount of classroom time spent on the ARIES modules varied from teacher to teacher, as did the amount of classroom time spent by the control group on the concepts or topics tested.

[9] In some instances control teachers told evaluators directly; in other cases the control teachers reported through their teaching colleagues (ARIES teachers).

[10] The themes addressed by question are (1-3) causes of shadow, outdoor shadow patterns, and time; (4-5) indoor shadow patterns; (6) day and night; (7) magnetism; (8) the apparent path of Sun; (9-10) the orientation of the Earth to the Sun; (11-12) vision and light; (13-14) scattering and reflection; and (15-16) prisms and refraction.