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The Effects of a Two-Year Molecular Visualization Experience on Teachers' Attitudes, Content Knowledge, and Spatial Ability

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A number of researchers have reported that students hold alternate conceptions concerning the particulate nature of matter (PNM) *(1–6)*. These alternate conceptions of the PNM conflict with the theoretical, particulate explanations that are given by chemists for most experimental chemistry data. Johnstone *(7)* described three components of chemistry: the macroscopic (what can seen with the eyes); the symbolic (equations and mathematics); and the submicroscopic (particulate) levels. Conceptual understanding of chemistry often involves understanding particulate behavior; another body of research has identified a gap between students' ability to respond to algorithmic versus conceptual questions *(8–9)*.

Evidence suggests that viewing particulate animations increases conceptual understanding *(10–11)*. Particulate animations come in a number of types: some are driven by mathematical equations (computational animations); some are artistic representations of phenomena (representational animations); others can allow or require student input or control (interactive animations) *(12)*. Burke, Greenbowe, and Windschitl *(13)* summarized the literature on the development and use of animations, noting that animations of short duration and use of multiple representation could be effective at promoting conceptual understanding. Velazquez-Marcano, et al. *(14)* reported that the order of animation versus demonstration did not matter for predicting the correct outcome of fluid experiments at the macroscopic scale. Either combination created the same predictive ability; however, the study found that using only one type of representation was not enough and that both were needed for maximum effect. Williamson and Abraham *(15)* suggest that animations may prompt the formation of dynamic, more expert-like mental models of the phenomena and that with static visuals students may fail to form particulate mental models or may form inadequate, static mental models.

Mental models are pictures or visualizations in the mind. Mental models can be of macroscopic objects that students have seen in the past (e.g., a beaker), or they can be of abstract things that cannot be seen (e.g., atoms or molecules). According to Johnson-Laird *(16)*, our level of knowledge is dependent upon our ability to construct mental models from our conceptual frameworks, which we can use to reason. Larkin *(17)* described differences between the mental models of experts and novices. The mental models of experts usually include both sensory, macroscopic data from the physical world **and** formal abstract dimensions of the phenomena, while novices usually have incomplete or inaccurate models. The ideas that experts are capable of more abstract thought, while novices are confined to thought about concrete objects are consistent with constructivist learning theory. Constructivism has its roots with Piaget and von Glaserfeld and holds these tenets *(18–20)*:

1. Knowledge is constructed from interactions with people and materials and is not simply transmitted
2. Prior knowledge impacts learning
3. Learning is context specific, especially initial understanding
4. Purposeful learning experiences are required to facilitate the construction of new knowledge structures or modification of old ones
5. The quality of thought differs for individuals; at a younger level, experience with concrete objects is required and only mental pictures of concrete objects, not abstract ideas, can be formed

Visualization has been emphasized since the turn of this century *(21)*. For example, the Gordon Research Conference on Visualization in Science and Education[1] explores the development and use of visualizations in the classroom. Visualization techniques to help students visualize particles and enhance formation of their mental models can take a number of forms, including the use of physical models, role playing, fixed computer models that rotate, dynamic computer models or animations, student-generated drawings or animations, and interactive computer models *(12)*.

Motivation to offer a workshop to help secondary teachers and college instructors infuse visualization techniques into their classrooms came from this theoretical framework. In order to promote this infusion, it was important to provide teachers with the underlying theory, demonstrations, protected practice (teaching lessons in front of small numbers of students or peers), and feedback, which are the components for successful teacher development activities identified by Showers, Joyce, and Bennett *(22)*. While we hoped that students would ultimately benefit from trained teachers, the question of what effects a visualization workshop would have on the teachers themselves was the basis of this study. Helping teachers learn content using visualization strategies was a goal of this workshop. The spatial abilities of the teachers became a research interest after encountering a review by Wu and Shah *(23)*: they compiled previous correlational studies of spatial abilities and chemistry learning. Spatial abilities were linked to the mastery of chemistry content by a number of studies *(24–25)*. These spatial abilities include mental rotations, hidden figures, and card rotation. Investigating any changes in attitudes towards teaching and learning, in chemistry content, and in spatial abilities of the workshop participants became the interest of this study.

Purpose

The purpose of this study was to examine the influence of the workshops on the attitudes, content knowledge, and spatial abilities of the participating high school and college teachers. The study addressed the following research question: "What effects does short-term, intensive molecular visualization training have on teachers' attitudes, content knowledge, and spatial abilities?"

Methodology

The Participants

Twelve participants completed the workshop. Of these 12, six were high school chemistry teachers, one was a two-year college chemistry instructor, and five were chemical education graduate students. Of the five chemical education graduate students, one had taught high school, two were seeking alternative certification to teach high school, one was interested in teaching community college, and one was planning to teach at the university level in that participant's country of origin.

The Workshops

The molecular visualization workshop consisted of two, three-week sessions held over two consecutive summers. This workshop was offered in conjunction with the Information Technology in Science (ITS) Center for Teaching and Learning at Texas A&M University, which was designed to enrich and diversify national standards-based instruction in K–12, undergraduate, and graduate education in science. The molecular visualization workshop met for three weeks each summer in half-day sessions (four hours) Monday through Friday.

During the first summer session, the goals were to:

- Introduce participants to molecular visualization materials available for education and research purposes (and available for free or at low cost)
- Investigate literature on student misconceptions of the PNM; state and national standards; and the effects of molecular visualization on student understanding
- Identify critical attributes of molecular visualization needed to enhance learning in light of the investigation of the chemical education research literature
- Allow participants to critique educational molecular visualization materials
- Produce and practice a professional development presentation to inform other teachers about one or more of the visualizations that could be used in the classroom
- Infuse molecular visualizations into participants' classrooms (This was a goal, although Williamson et al. *[26]* discusses the differences between the intended versus actual use and the identified barriers to the use of molecular visualizations in the classroom.)

The products of the first summer session included professional development materials to use in a presentation to other teachers. These materials included a presenter's guide, handouts, and so forth, needed for the audience.

During the following academic year, workshop participants were to deliver their professional development session to at least five other teachers, gather feedback about the session, edit the materials, and submit the final versions of the presenter's guide and audience materials. Participants were asked to journal their use of molecular visualizations and record their experiences during the academic year. We expected that participants would use molecular visualizations in the classroom and would also help other instructors to use them as well.

During the second summer session, the goals were to:

- Move participants toward more expert use of a few molecular visualization materials available for education and research purposes (and available for free or at low cost)
- Continue to investigate the literature concerning: (a) student misconceptions of the PNM; (b) state and national standards; and (c) the effects of molecular visualization on student understanding
- Continue to critique educational molecular visualization materials
- Produce and practice-teach a learning cycle incorporating a molecular visualization in one or more of the phases

The products of the second summer session included a student and teacher version of a learning cycle. A learning cycle is an instructional strategy derived from constructivist learning theory, consistent with the nature of science, and has three sequential phases *(27)*. The titles of these phases have changed with various curricula; nonetheless, the basics include:

1. Exploring and gathering data: students are actively involved in experimentation and gathering data on variables
2. Discussion and concept invention: the concept invention phase is an inductive activity involving logical organization, comparison, and interpretation of data, resulting in a generalization about the variables
3. Expansion and application: students are asked to apply the generalization in a new situation or examine another aspect of the concept

Molecular Visualization Materials Used

A number of types of molecular visualizations were used. These included programs to view and rotate molecules, those to draw molecules, and those to construct animations. We also used animations produced by others that could be accessed via videotape, CD-ROMs, and the Internet. Because educators do not typically have access to costly computer programs, we made sure that only low-cost or no-cost programs and materials were used. See List 1 for the visualizations used in the workshop.

List 1. Visualization Resources Used in the Workshop

Types or Sources	Resources
Software to view and rotate multidimensional objects	Rasmol *(28)* Chime *(29)*
Software to draw molecules	ISIS Draw *(30)*
Videotape animations	ChemistryAnimation Project *(31)*
CD-ROM animations	Chemistry Animations CD *(32)* ChemFile Interactive Tutor *(33)* Publisher CDs
Software to create animations	ChemSense *(34)*
Internet	Web sites offering visualizations

The Instruments

The reasoning ability level of the participants was measured using the Group Assessment of Logical Thinking Test (GALT).[2] The GALT tests six types of logical thinking: conservation, control of variables, correlations, proportions, combinations, and probability *(35)*. Scores from the GALT range from 0–12.

Attitudes toward learning and teaching were collected with a survey that was given before and after each summer session. We have used this learning and teaching survey for a number of years with preservice and inservice teachers to gauge changes in preferences. The learning portion of the survey contains 16 statements about learning preferences that require responses on five-point Likert scale from strongly agree to strongly disagree. The ideas for the learning items were drawn from the semantic differential items on the Birnie–Abraham–Renner Quick Attitude Differential *(15, 36)*. The teaching portion of the survey uses a similar five-point Likert scale for 24 items dealing with teaching style. These items describe teaching behaviors consistent and inconsistent with inquiry-based teaching. These items were drawn from those on the Learning Preferences Variables Inventory *(37),* but redesigned to reflect the teacher's viewpoint. Data about attitudes towards the workshop were also collected using an end of summer survey given at the conclusion of each summer session. Additional evidence was gleaned from online directed writings, assigned each night.

Content knowledge was assessed using the General Chemistry Conceptual Examination from the ACS Examinations Institute *(38)*.[3] These examinations were scored based on the number of correct questions out of the 60 available.

Spatial ability was measured using a number of instruments. A mental rotation test *(39)* was used to gage 3-D rotation ability. This test has 20 items and can have a maximum score of 40. A hidden figures and a card rotation test *(40)* were also used. The card rotation test is a 2-D rotation task, with maximum scores of 160. The hidden figures test has a maximum score of 400. A combination examination containing 3-D rotational tasks and card folding tasks was given,[4] with scores between 0–100 *(41)*. The administration schedule of all instruments is given in Table 1.

Results

Participants' attitudes towards teaching and learning were positive on positive statements and negative to undesirable statements. Table 2 summarizes the six items that had significant changes in the participants' attitudes as measured by the learning and teaching survey. Significant differences were calculated using a two-tailed paired *t*-test *(42)*. Two statements on learning and one statement on teaching changed significantly from pre-to-post Summer I. In post-survey responses, participants more strongly agreed that working with others helped them learn the

Table 1. Assessment Tools Administered, by Workshop Timing

Assessment Tools	Pre-Summer Workshop I	Post-Summer Workshop I	Pre-Summer Workshop II	Post-Summer Workshop II
GALT *(35)*	×			×
Learning and teaching survey	×	×	×	×
End of summer workshop survey		×		×
ACS conceptual examination *(38)*	×	×	×	×
PsychTests *(41)*	×	×		
Mental rotations test *(39)*	×		×	×
Hidden figures *(40)*	×		×	×
Card rotation *(40)*	×		×	×

Table 2. Learning and Teaching Survey Results Compared by Session Timing

Survey Statement (1 = strongly agree; 5 = strongly disagree)	Pre-Summer Workshop I	Post-Summer Workshop I	Pre-Summer Workshop II	Post-Summer Workshop II
Learning-Focused Statements for Response				
Working with other students helps me learn the material.	2.33 (0.89)	1.75 (0.62)		
Others pressure me to do well in class.	3.58 (1.00)	2.92 (1.16)		
The content of this class will help me perform in the classroom.	2.09 (0.54)			1.58 (0.51)
Teaching-Focused Statements for Response				
I would be interested in working in an experimental curriculum.	1.75 (0.62)	2.08 (0.29)		
I enjoy manipulating science equipment.			1.92 (0.29)	1.50 (0.52)
In the classroom, I fear experiments won't turn out as expected.			3.67 (0.78)	4.00 (0.74)

Note: Average scores reported (*N* = 12; standard deviations in parentheses). All rows are statistically significant (two-tailed paired *t*-test, $p < 0.05$).

material and responded more positively that others pressured them to do well. After the first summer, participants were less interested in working in an experimental curriculum. These three items significantly changed after the first summer.

Two statements on teaching changed significantly from pre-to-post summer II. Participants more strongly agreed that they enjoyed manipulating science equipment and disagreed that they feared experiments would not turn out as expected. These two items did not significantly change after summer I.

One statement on learning showed a statistically significant change from pre-summer I to post-summer II. Participants more strongly agreed that the content of the class would help their classroom performance. There was no difference from the end of the first summer session to the beginning of the second summer session.

Two end-of-summer survey questions addressed participants' beliefs about the effect that training with the visualization programs had on their knowledge of chemistry. After the first summer's activities, participants agreed that the programs helped them learn chemistry content, although they were more neutral on the matter of technical expertise versus content learned (see Table 3). The following summer, that gap narrowed with participants' tendency to agree that more technical expertise was gained during summer II.

There was a mismatch between their opinions about content learning and their performance on the ACS conceptual examinations. The average group scores (out of a possible 60) are summarized in Table 4. No significant differences are seen between any administrations of this measure of content knowledge. With the idea that participants may perform better on visual questions, the conceptual examinations items were categorized into visual and non-visual tasks. This categorization was completed by one author and compared to an inter-rater (a second evaluator). Any initial discrepancies were discussed, resulting in 100% agreement. No significant changes were seen considering only visual tasks or the examination in its entirety.

Of the four instruments used to measure spatial ability, only the PsychTests was given pre- and post-summer I. Based on this measure of participants' 3-D rotation and folding abilities, the data show a significant increase (Table 4). Between the first and second summer sessions, access to the PsychTests site was no longer free, so it was not used during summer II.

The remaining three spatial ability tests were administered pre-summer I, pre-summer II, and post-summer II. Time constraints on the final day of summer I did not permit the investigators to administer these tests; however, these tests do allow other comparisons. Pre- and post-summer II were compared on 2-D rotation, 3-D rotation, and hidden figure abilities. No significant difference emerged in the participants' 2-D rotation abilities, although significant increases were found in hidden figure and 3-D rotation abilities. No differences were evident between the pre-summer I and the pre-summer II scores on any

Table 3. Comparative Results from the End of Workshop Surveys and the ACS Conceptual Examination

Assessment Instrument	Pre-Summer Workshop I	Post-Summer Workshop I	Pre-Summer Workshop II	Post-Summer Workshop II
End of Workshop Learning and Teaching Survey Statements for Response (1 = strongly agree; 5 = strongly disagree; SD in parentheses)				
"I learned chemistry content through the visualization programs."		**1.85 (0.55)**		1.90 (0.57)
"I learned more technical expertise with computers and programs than I did chemistry content."		**2.62 (0.96)**		2.40 (0.97)
ACS Conceptual Examination (average points achieved out of 60 points possible; SD given in parentheses)				
	43.71 (8.02)	43.50 (7.84)	44.33 (8.67)	44.73 (7.55)

Note: Average scores reported ($N = 12$). Bold type indicates statistically significant results ($p < 0.05$).

Table 4. Comparative Results from Spatial Ability Measures, by Workshop Session

Instrument/Task Measured	Pre-Summer Workshop I	Post-Summer Workshop I	Pre-Summer Workshop II	Post-Summer Workshop II
PsychTests[a]				
Folding with 3-D rotation	**40.00 (14.77)**	**56.67 (16.70)**		
Card Rotation[b]				
2-D Rotation	107.08 (24.23)		104.00 (35.68)	118.83 (28.54)
Hidden Figure Task[c]				
Reveal hidden figure	215.58 (42.62)[d]		**218.54 (49.94)**	**277.50 (54.28)**
Mental Rotation Test[e]				
3-D rotation	20.08 (7.89)		**16.08 (6.08)**	**22.17 (9.45)**

[a] Average points ($N = 12$) achieved out of 100 points possible; SD given in parentheses. [b] Average points ($N = 12$) achieved out of 160 points possible; SD given in parentheses. [c] Average points ($N = 12$) achieved out of 400 points possible; SD given in parentheses. [d] Significant difference between pre-summer workshop I and post-summer workshop II scores. [e] Average points ($N = 12$) achieved out of 40 points possible; SD given in parentheses. Bold type indicates statistically significant results ($p < 0.05$).

measure. Differences between the pre-summer I scores and the post-summer II scores were also checked. A significant difference emerged only in hidden figures between pre-summer I and post-summer II, with means of 215.58 and 277.50, respectively.

The effect size (the difference in means, divided by the standard deviation) for each significant difference in spatial ability measures was calculated. The standard deviation for the latter measure was used, as these all had larger standard deviations. The effect size indicates how many standard deviations of change are seen. For the PsychTests measure pre- and post-summer I, the effect size is 1.00, meaning that abilities increased an average of one standard deviation on the post-summer I test. For the hidden figures measure pre- and post-summer II, the effect size is 1.09, indicating that post-summer II results rose on average 1.09 standard deviations above the pre-summer II score. The effect size for the mental rotation test pre- and post-summer II was 0.64, indicating that the post-summer II scores increased 0.64 standard deviations above the pre-summer II scores. Finally, the hidden figures score for beginning to end of the project (pre-summer I to post-summer II) had an effect size of 1.14.

Discussion

The goal of this study was to investigate any possible changes in teachers' attitudes, content knowledge, and spatial ability as a result of a two-year visualization workshop experience that included three-week sessions each summer. Few significantly different changes in participants' attitudes were observed. This finding may be related to the participants' high caliber. Most had gained experience with inquiry-based teaching and learning by taking a course taught by one of the authors. Since parts of the learning and teaching survey were patterned after an instrument that gauges one's orientation toward inquiry, the results are not surprising. Teacher attitudes were initially positive toward the positive items on the survey and negative toward the negative items on the survey. The significant differences in participants' attitudes that did emerge may be due to attributes of the workshop as described below.

The differences seen following the first summer session speak to the *intensive* nature of the experience for some, if not all the participants. When participants were asked on the end-of-summer survey what their least favorite feature of the workshop was, one teacher responded:

> Just keeping things sorted out mentally was difficult for me. I felt that I was not able to keep up the pace of learning so many new functions and so much information everyday. Now that I have been home and sorted through some of my stacks some of it is less blurry than I thought it would be but I know I will have many questions and need much help to finish the list of things to do now that we are home.

This sentiment may explain why participants were less interested in working with an experimental curriculum. Conversely, while in the protected environment of the workshop, participants seemed to take comfort in the fact that they were working with one another and encouraging one another to do well. (Participants more strongly agreed that working with others helped them learn the material and responded more positively that others pressured them to do well.) One participant responded with the following statement in the directed writing:

> I learned so much that I can use in my classroom. Much of what I am talking about I learned during group discussions, even over lunch or dinner.

Participants were more positive towards manipulating science equipment and less fearful about the outcome of experiments following the second summer session. These changes may be easily explained by the inquiry nature of the product asked for by the end of this session. These responses are the desired outcome of any inquiry-based teacher training (the production of teachers who are less afraid to perform hands-on activities with their students).

No changes in content knowledge were observed as measured by the ACS conceptual examination results. While teachers believed that they did learn content, this was not illustrated in the content instrument used. It is possible that this instrument was unable to measure the type of content learned in this visualization workshop.

Significant changes were seen in the participants' spatial abilities. The most interesting finding of the study was the oscillating nature of participants' spatial abilities. During the three-week session in summer I, spatial abilities significantly increased as measured by folding and 3-D rotation tasks. During the academic year, teachers were to use visualizations in their classrooms and present one of the molecular visualization programs to other teachers. Williamson, et al. *(26)* identified barriers to the use of molecular visualizations that classroom teachers experienced when trying to implement these visualizations in the classroom; these included Internet access, computer lab availability, lack of preparation time, technical support availability, and administrative support availability. At the beginning of summer II, participants had about the same abilities (2-D rotation, hidden figures, and 3-D rotation) as they had at the beginning of summer I. Once again, during the second, three-week session, spatial abilities increased significantly as measured by the hidden figures and 3-D rotation tasks.

Conclusions and Implications

In this study, content knowledge and attitudes did not change appreciably; however, the data show that spatial abilities increased with use. Some cognitive measures are considered relatively static, for example, IQ *(43)* and learning styles *(44)*. In contrast, it is important to note that spatial ability seems to change more easily, as it did in a three-week period for those in this study. These changes in spatial abilities should be examined in light of the participants' activities. The three-week sessions involved intensive, half-day sessions, in which the participants worked with 3-D models and computer-generated images. These daily, consistent sessions seemed to play a role in an increase in spatial abilities. During the academic year, participants lost the gains in spatial abilities. This loss may be due to the fact that the participants were instructing with visualizations, not using the visualizations themselves or not personally using the visualization as often or as intently. With this evidence, spatial ability seems to increase with use and decrease when not used. The old adage, "if you don't use it, you lose it", might hold here.

Research in this area must be conducted with different audiences and in different contexts, including use of a more sensitive content instrument. Research with student populations should be conducted to discover whether the same results are observed as with the chemistry instructors in this study. The implications may be that it is not so dismal for those students who have low scores in spatial abilities. With practice, these abilities may increase, as they did in the context of this study. Instructors of chemistry need to understand that students with low spatial ability should not be dismissed as unable to learn spatial relationships like molecular geometry, stereochemistry, and so forth. As in this workshop, the power of protected group-learning experiences with visualizations should not be overlooked. With increased use, the spatial abilities of our participants increased; with less use, their spatial abilities decreased.

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Notes

1. More information is available at the conference's Web site: *http://www.grc.org/conferences.aspx?id=0000385* (accessed Feb 2008).
2. Example GALT test for course use. *http://science.palomar.edu/igesc/galt/galt-post.html* (accessed Feb 2008).
3. Both the 1996 and 2001 versions were used. The 1996 version was used pre-summer I and post-summer II, while the 2001 version was used in the post-summer I and pre-summer II assessments.
4. This test was free at the time we used it: *http://www.psychtests.com/tests/iq/spatial_iq_r_access.html#h* (accessed Feb 2008).

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