"The Mole Environment"−Development and Implementation of Studyware

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The mole is a fundamental concept in chemistry. It is a basic measurement unit and is used for stoichiometric calculations, expressing solution concentrations, equilibrium constant, and pH. Many students have difficulties in understanding and applying the mole concept. Students therefore adopt a variety of algorithmic techniques for solving problems provided as predefined templates in books, classes, tests, and matriculation examinations. Consequently, some of the students are not capable of solving complicated problems which do not conform with any of the templates they recognize. Having identified these problems, we have developed a studyware referred to as "The Mole Environment". This studyware integrates two approaches: (1) continuous, real-time feedback to the student responses and (2) incorporating real-life problems from the domains of environmental studies, chemical industry, and medicine. The studyware includes problems at several cognitive levels which progress in difficulty and complexity. The development, implementation in high school and in-service teachers' training, and evaluation are presented and discussed.

INTRODUCTION

The mole is a fundamental concept in chemistry. It is a basic measurement unit and is used for such operations as stoichiometric calculations, expressing solution concentrations, equilibrium constant, and pH. Many students have difficulties in understanding and applying the mole concept (Duncan and Johnstone;[1] Herron and Greenbowe;[2] and Schmidt[3]), resulting in difficulties in solving problems in chemistry in general (Gabel and Bunce;[4] Staver and Lumpe;[5] and Staver and Lumpe[6]). Students therefore adopt a variety of algorithmic techniques for solving problems provided as predefined templates in books, classes, tests, and matriculation examinations. These techniques frequently enable the algorithmic-oriented students to provide correct answers for such template-based questions, which are, in general, questions of lower level and/or have an easily identifiable algorithmic structure. Consequently, some of the students are not capable of solving problems at a higher level or those that do not conform with any of the templates they recognize, which they were trained to solve.

Among the most important learning outcomes that good teaching should be aiming at are problem solving and decision making abilities (Zoller[7]). Thus, the following two major complementary trends characterize many science education reforms: (1) the development of students' thinking and problem-solving abilities in a specific context and (2) the construction of a deep conceptual understanding of a topic in a global context (Zoller, Lubezky, Nakhleh, Tessier, and Dori[8]). Problem solving in chemistry could be more meaningful if problems were presented in a way that emphasizes the relations between the problem, the phenomenon and its microscopic representation (Gabel and Bunce;[4] and Dori, Gabel, Bunce, Barnea, and Hameiri[9]).

Aiming at improving students' problem solving abilities, while recognizing the importance of the global context (or viewpoint) discussed above, we have designed and developed a studyware that is specifically targeted at addressing these issues. Our studyware differs from traditional computer assisted instruction (CAI) systems in that it provides an active and exploratory approach to learning, while guiding, monitoring, and improving student's performance (Dori, Dori and Yochim;[10] and Dori[11]).

In order to solve quantitative problems in a meaningful way the student must be challenged to achieve and demonstrate deep understanding of the mole concept. Morrissey, Kashy, and Tsai[12] and Yalcinalp, Geban, and Ozkan[13] have described a CAI system dealing with the mole topic and quantitative chemistry. The CAI system enables the instructor to create problem sets for each student and provides immediate feedback while reducing the impersonal nature of teaching in large classes.

The specific context we address is the mole concept and related problems, while the global context is "Science-Technology-Environment-Society" (STES) (Zoller[14]). The integration of the two contexts strengthens both of them reciprocally: The mole is used in a practical treatment for a rigorous, quantitative treatment of environmental issues, while STES-related problems are addressed using a scientific, well-founded methodology, based on fundamental concepts in chemistry.

RESEARCH OBJECTIVES

Taking into account the considerations discussed above, the objectives of our research have been defined as follows.

*Develop a studyware in which the "Science-Technology-Environment-Society" (STES) issue is integrated with the mole concept.

*Introduce and teach the mole concept within high school chemistry using the "Mole Environment" studyware.

*Overcome problems stemming from the existence of "algorithmic templates" associated with quantitative chemistry.

*Explore attitudes of students and in-service teachers toward the studyware itself and toward integrating the mole and STES concepts.

CHARACTERISTICS OF "THE MOLE ENVIRONMENT" STUDYWARE

The Mole Environment studyware has a *shell* structure, into which different contents can be input. The *author's*

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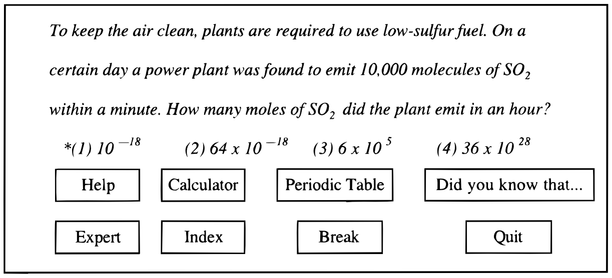

Figure 1. An example of a problem that integrates the mole concept with environmental real-life stories. *represents the correct answer.

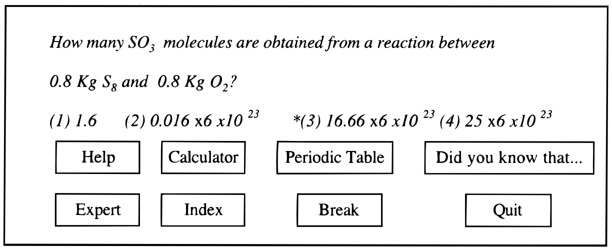

Figure 2. A problem from a higher difficulty level which requires understanding mass calculations with limiting reagent.

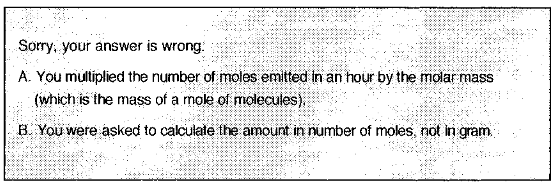

Figure 3. An example of a feedback window which opens upon clicking the second distractor (64×10^{-18}) in Figure 1.

compartment enables the teacher/researcher set the contents. The topic of our studyware is the mole concept integrated with environmental real-life problems. Examples of such problems are presented in Figures 1 and 2. The teacher/researcher can also define and change the question level, create new questions, and delete others.

The *student's compartment* is the environment through which the student interacts with the studyware. The studyware is built around problems arranged by increasing difficulty and complexity of sublevels and levels. Each level contains 18 multiple choice problems set in six difficulty sublevels containing three questions each. The studyware advances the student from lower to higher sublevels and levels based on her/his achievements. After clicking the right answer, he/she will receive another problem at a higher sublevel. Only after choosing the correct answers for five questions is the student advanced to a higher level.

The multiple choice problems contain carefully selected items (distractors) designed to identify difficulties and misunderstandings. Feedback is given for an incorrect response by explaining why the answer is wrong (see Figure 3 for example). The student is given another chance to solve the same problem again, and later a new problem at the same sublevel presented. For a correct student's response to a question, the correct answer is briefly summarized.

The studyware contains three types of teaching aids:

- *Content-oriented:* definitions, explanations, and *"did you know that..."*. As an example for "did you know that...", the window in Figure 4 was opened upon clicking the "did you know that..." button while viewing the problem presented in Figure 1.
- *Technical:* periodic table, calculator, and unit conversions.

Teacher-oriented: level symbol—a cube with a different color for each level at the corner of the screen, which enables the teacher to easily see at what level each student is. This is an opportunity for the teacher to approach and help the student whose pace is slower than that of his/her peer.

Upon completion, the student receives a summary of her/his activity and achievements, while the teacher can request a report on each student's activity, mistakes and their frequency as well as statistical analysis.

IMPLEMENTATION

The studyware was developed for PC and used at the first stage of the research by both students and teachers. The research sample included 90 students from four classes. Two classes were 11th ($N = 16$) and 12th grade ($N = 18$) science major classes who refreshed the mole topic. They served as a pilot group in the development process and provided comments and suggestions for improving the studyware and the stories. Two other classes were 10th grade classes who studied the mole for the first time. One of them was a class of science majors ($N = 34$) and the other—non-science majors class ($N = 22$). Also included in the research sample was a group of in-service teachers ($N = 20$), who reviewed the studyware and provided further feedback.

Some of the remarks the pilot group and teachers made contributed to improving the studyware shell and the authoring process. Following comments we added to the shell such features as the colored cube level symbol, divided each level to sublevels, and designed the same appearance to system's response for positive and negative feedback, thereby avoiding potential embarrassment of students who do not wish their peers to know their answers are wrong.

Participants responded to a Likert type attitude questionnaire. They were asked about (1) their attitudes toward working with the studyware; (2) understanding the mole concept; and (3) the integration of the mole concept with solving real-life problems. In addition, some of the participants were also interviewed. The questions for (2) and (3) were formulated as follows:

"Working with the studyware improved my understanding of the mole concept" and

"The real-life problems are interesting and contribute to the understanding of the topic"

RESULTS

The statistical results are presented by bar charts depicting the number of students' and teachers' responses to specific questions vs their level of agreement to each item presented. Figure 5 presents the 10th graders' response to the two following items regarding the effect of working with the studyware on their understanding of the mole concept:

(1) I feel that I understand better the mole topic.
(2) Working with the studyware did not improve my understanding of the mole topic.

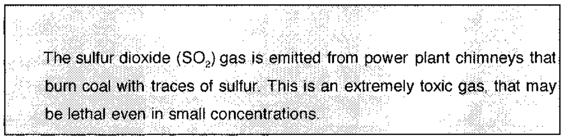

Figure 4. An example of a window which opens upon clicking the "did you know that..." button for the problem in Figure 1.

(Item 2 was inversely scaled to account for the negative formulation). The diagram shows that 65% of the nonscience majors and 56% of the science majors indicated that the studyware contributed to their understanding of the mole concept. The 19% of the science major students who chose the "totally disagree" and "disagree" typically noted that the studyware did not improve their understanding because they already understood the topic from teacher explanations in the classroom.

Figure 6 presents the 10th graders' and teachers' responses to the following two items concerning the integration of STES stories in the studyware:

(1) The real-life stories are interesting.

(2) The real-life stories contribute to understanding the mole topic.

Figure 6 shows 45% of the science majors disagreed, 26% had no opinion, and the rest (29%) agreed to the two statements. None of the nonscience majors totally disagreed, and only 15% disagreed. Some of the 40% non-science majors who chose "no opinion" said that while many of the stories were interesting, sometimes they distracted them from the main point of the problem.

Forty-five percent of the nonscience majors agreed that the real-life stories were interesting, which shows that even with the difficulties they encountered, they enjoyed and felt that the stories gave "some spices" to the "boring" calculations, as they stated in their own words.

Teachers' responses were similar: 55% agreed, 30% had no opinion, and the rest (15%) disagreed. Several teachers indicated in the interviews that integrating real-life stories is the best way to teach and study problem solving in chemistry.

Some of the 10th grade student responses in the interview are presented below.

*"I feel I studied much more because I learned at my own pace."

*"The real-life stories are sometimes annoying, but some of them were new and interesting for me."

*"I am embarrassed to ask questions in class and here I could quietly call the teacher and she helped me. It was good."

*"At the beginning it was fun, but at the end of the session my brain was completely squeezed out..."

*"In class it was possible to make some noise and disturb, but here everyone is busy and you must concentrate all the time. This is not good."

SUMMARY AND FURTHER RESEARCH

Overall, the studyware was very well received by students and teachers alike, and, at least according to the participants' responses, it contributed toward increased understanding the mole concept. The effect was more noticeable on nonscience majors than on science majors, because the latter had good grasp of the topic even prior to using the studyware.

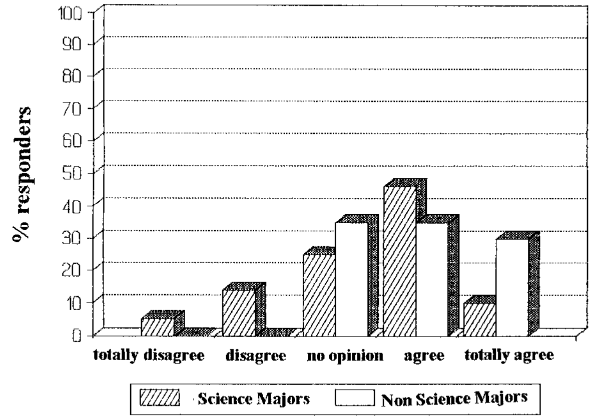

Figure 5. A bar chart of 10th grade student responses to the two items related to the effect of working with the studyware on improving students' understanding of the mole concept. The statement responded to was "working with the studyware improved my understanding of the mole concept".

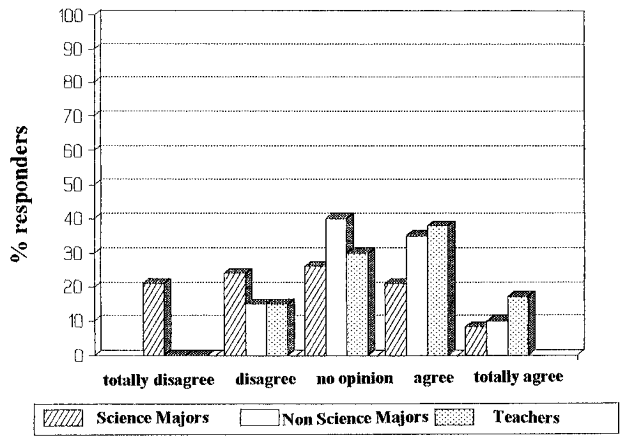

Figure 6. A bar chart of 10th grade students' and teachers' responses to the two items related to the real-life stories. The statement responded to was "The real-life problems are interesting and contribute to the understanding of the topic".

As for teacher preparation, we recommend integratation of more computer usage into teachers' training and introduce more environmental studies to increase the link to real-life issues and the ability to solve problems of nonalgorithmic nature.

Further research should verify that the favorable attitude toward the studyware applies to larger samples and that there is an actual improvement in achievements and in increased problem solving ability. Likewise, further validation should be made regarding the extent of internalizing the environmental aspects.

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