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School Chemistry Vs. Chemistry in Research[1]: An Exploratory Experiment

Clarisse L. Habraken,[2,8] Wim Buijs,[3] Hens Borkent,[4] Willy Ligeon,[5] Harry Wender,[6] and Marijn Meijer[7]

This report describes a study which explores, from the out-of-school student viewpoint, why students are not studying chemistry anymore. In a 2-day stay at a research institution three groups of graduating high school students from different schools, together with their chemistry teacher, were confronted hands-on with molecular modeling in industry and in university. Each of these volunteer students had agreed to write an essay on "School Chemistry Vs. Chemistry in Research." These essays were evaluated together by the students, the teacher, and the researcher in a meeting at their school. The opinion of the students show that school chemistry does not convey today's chemistry in research and in industry. At the computer screen the students demonstrated their skill in performing molecular modeling experiments. Moreover, at the computer screen, chemistry was fun and easier to understand. Now we begin to see the solution: our students are also our teachers.

KEY WORDS: Out-of-school learning; visuospatial talents; chemistry; school chemistry; molecular modeling.

INTRODUCTION

Why do high school graduates turn away from chemistry? The decline in the number of students choosing chemistry in tertiary education is a continuing concern for chemists and chemistry educators. Many causes have been suggested (De Vos *et al.*, 1993, 1994; Hammond, 1977; Lagowsky, 1988; Roberts, 1995, 2001; Smithers, 1989; Stevenson, 1995). The changes that were then introduced were of little or no avail. Students are still, despite our best efforts, voting with their feet and getting out of chemistry (Johnstone, 1997). It is remarkable how far we seem to be from where we want to be in terms of student learning and attitudes (Runge *et al.*, 1999). Clearly, there is no consensus on how best to achieve improved science education in general, or possibly even what those goals are (Pine, 1998).

Recently, an entirely different approach to this problem was addressed by collating *school chemistry* with *today's chemistry* from the perspective of today's out-of-school learning (Habraken, 1996, 1997, 2000). *Today's out-of-school learning*, from kindergarten age to senior high school students, is dominated by television, video, and many new other applications of PC technology (Davies *et al.*, 1990; Rushkoff, 1997). Today's children grow up acquiring a highly developed visuo-spatial intelligence and talent, and this is the talent that involves visual memory and the mental processing of visuo-spatial information (Habraken, 2000; Smith, 1993).

In *today's chemistry*, formal pictorial presentation is *the* dominant way of thinking. Throughout the chemical research world, scientists communicate with

[1]Part 4 of "Perceptions of Chemistry"; Parts 1–3 see Habraken, 1996, 1997, 2000.

[2]University of Leiden, Gorlaeus Laboratory, POB 9502, 2300 RA Leiden, The Netherlands.
[3]DSM Research, The Netherlands.
[4]CAOS/CAMM Center, Katholic University Nijmegen, Nijmegen, The Netherlands.
[5]Aquinocollege, Leiden, The Netherlands.
[6]Thijcollege, The Netherlands.
[7]Newmancollege, The Netherlands.
[8]To whom correspondence should be addressed; e-mail: habraken@chem.leidenuniv.nl

2D and 3D molecular structures which they interpret to predict physical properties. Experiments are discussed, understood and designed at the computer screen (Luisi and Thomas, 1990; Davies *et al.*, 1990). Thus, chemistry has evolved from a science dominated by mathematics and traditionally considered *the* scientific language, into a science highly dependent on *visuo-spatial intelligence*. Over the last 125 years, thinking in chemistry has shifted from the logical-mathematical to the *logical-visuospatial* (Davies *et al.*, 1990; Habraken, 1991, 2000; Luisi and Thomas, 1990). So what is important *today* is the degree to which both chemists *in* chemistry and our potential chemists are now fully conversant in communicating, arguing, and thinking visuo-spatially.

Today's school-chemistry, as of old, is expressed mainly in symbols and numerical data. All descriptions and explanations occur in *verbal* and *numerical* language. Modern school texts do contain a plethora of pictures, but these are really *illustrations*. Chemical reactivities such as oxidation, reduction, and acidity are characterized by numbers only. Thus the progressive thinking in today's chemistry is not taught and, more worryingly, todays highly developed visuo-spatial intelligence of the next generation of chemists is not addressed.

Accounting thus for the alarming increase in the numbers of graduating high school students turning away from chemistry, we decided to challenge the views of both senior students and their chemistry teachers in an out-of-school setting. This report describes the results of three such exploratory projects. Three different high schools, each provided a group of volunteer students together with their chemistry teacher. Each group, on a 2-day visit, was confronted hands-on with computer molecular modeling in today's chemistry. One group went to the National computer molecular modeling center at Nijmegen University; while the other two groups went to the DSM-Research Center (in Geleen).

The 2 days of this project were spent together to enable wide ranging discussions fostering real collaborations among the participants. A crucial feature of the projects in this study is that all participants, the students, the chemistry teachers, and the industrial researcher are all *collaborators* as well as *subjects*. Together, they had the assigment to investigate the question "why students taking chemistry in senior high school have decided not to continue chemistry in tertiairy education" (Habraken *et al.*, 1992). Each of the volunteer students agreed to write an essay on "School Chemistry vs. Chemistry in Research." The students were not influenced by any form of prejudice from the experimental design. In the discussion section, some of our findings are discussed also in the light of like findings reported in a seminal paper published during the preparation of our report (Ealy, 1999).

PROCEDURE

Three groups, denoted Group A and Group B-1 and B-2, of senior high school students (~18 years old) and each from a different high school were introduced to the use of computer modeling in today's chemical research. With their high school chemistry teacher and with use of hands-on experiments, they were exposed to molecular modeling as a tool to learn, to understand, and to explore in today's chemical research. By accepting the invitation, each student had agreed to write a report on, "School Chemistry vs. Chemistry in Research." The students had not been asked what they were planning to study after graduation from high school. They had been informed about the continuing decrease of the number of high school graduates choosing chemistry in tertiary education. As it turned out, none of these 29 students favored chemistry.

Group A

In November 1998, 13 students from Thijcollege (Oldenzaal) spent 2 days at CAOS/CAMM, the National computer facility at Nijmegen University. All of the time they worked in a computer teaching room. The modeling program that they used was WetCHE, the on-line teaching program developed in CAOS/CAMM (1998) for university teaching. The students, working in pairs, were assigned to perform two conformational analysis studies. In the first day, the relative stability of conformations was investigated for isopropylcyclohexanes up to all-trans-1,2,3,4,5,6,-hexa-isopropylcyclohexane, see Fig. 1 (Goren and Biali, 1990). The second day was scheduled for researching on the computer the preferred conformation found of a chiral molecule under investigation in the division of organic chemistry at Nijmegen University.

Group B-1

Seven students of Newmancollege (Breda) spent 2 days in November 1998 at the Research Laboratory of DSM-Research, one of the large international

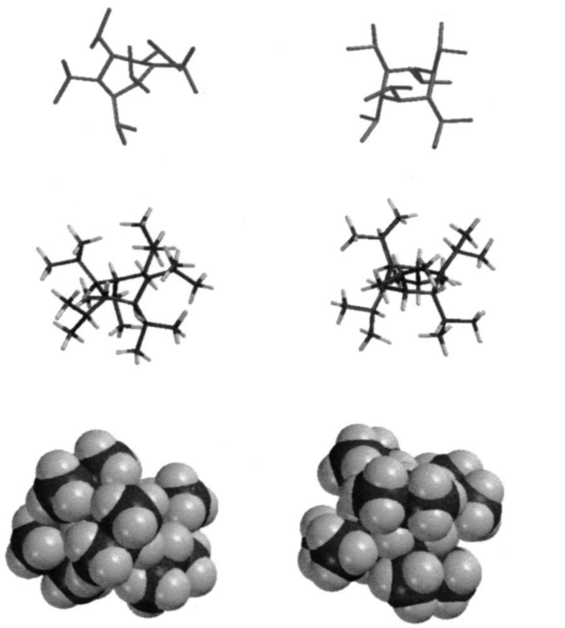

Fig. 1. All equatorial and all axial trans-1,2,3,4,5,6-hexa-isopropylcyclohexane depicted in tube (hydrogens hidden) model, in tube (hydrogens shown) model and in space-filled model.

industrial laboratories in The Netherlands. They were introduced to the computer modeling program PC Spartan Plus currently in use at DSM-Research. The computer experiments were performed with ten PC's especially converted for this experiment. The students were assigned a number of different modeling experiments, which ranged from structural explorations to electron densities and electrostatic potentials on so-called 'isovalue surfaces" (see Fig. 2 and 3). These experiments were taken from the Spartan tutorial designed for use in undergraduate university chemistry courses (Wavefunction, 1996). In addition, they were also taken on two site excursions; one was to the DSM Caprolactam Plant, and one to a DSM Research project.

Group B-2

In January 2000, a group of nine senior high school students and their chemistry teacher from Aquinocollege (Leiden) also went to DSM-Research. They were assigned the same computer experiments as Group B-1. They were taken on a tour of the huge

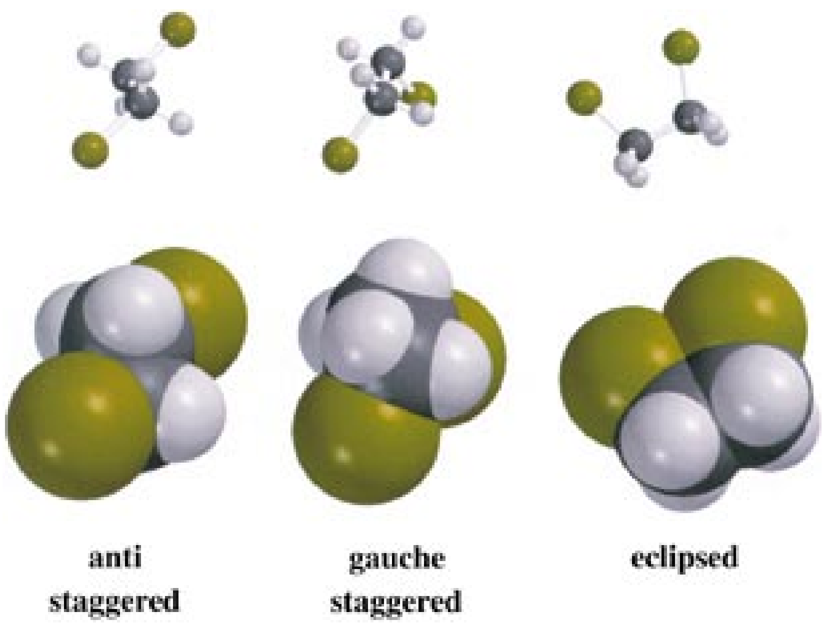

Fig. 2. Three conformations of 1,2-dichloroethane. "By changing from ball-and-spoke to space-filled model you obtain an overall picture of the spatial structure of a molecule. Also, the differences between stereoisomers become clear. Thus, you see two chlorine atoms bumping into each other" (quotes from the report of Kim Vermonden).

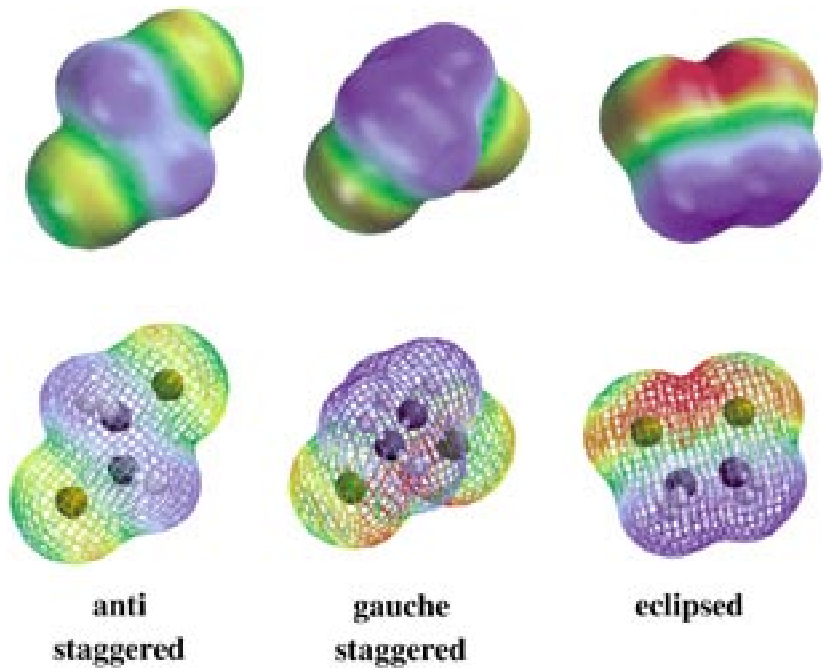

Fig. 3. Three conformations of 1,2-dichloroethane conveying color-coded electrostatic potentials on the electron density isosurface (corresponding to the van der Waals contact surface), thereby, indicating which of the accessible regions on a molecule are electron rich and which are electron poor (Wavefunction, 1996). In the second row, with the surface depicted in *mesh* style, the ball-and-stick model is observable too. Quote from Kim Vermonden's report: "Also interesting is the electrical charge distribution. The electron potential map makes clear why some compounds repel or attract each other."

DSM industrial site and visited a research laboratory project that investigates the DSM carpet Nylon-6 recycling process.

Essay writing guidelines: The assignment was to write an essay under the title "School Chemistry vs. Chemistry in Research." The technical guidelines that they were given were to keep within a total of 800 words, with a maximum for text and pictures of 3 pages.

Project evaluation meeting: After 4 weeks, each project group, the volunteer students, their chemistry teacher, and the researcher came together in the school to discuss and evaluate the students essays.

RESULTS

Looking at the 29 essays, in conjunction with the evaluation discussion held at a later date, brings us to the following conclusions (I–VII), summarizing student reactions and remarks on "School Chemistry vs. Chemistry in Research." Group VIII contains some of the teacher's observations. The number assigned to pronouncements and comments has no relation to their frequency. These direct quotes are representative of similar comments on a general theme.

I. On Chemistry
   1. So, chemistry is not just laboratory experiments. It is not just wasting time doing a few little experiments, in a lab playing around with a bunch of small stuff.
   2. Chemistry then is not just calculating stupid acid–base reactions and equilibria and number-juggling only, (BINAS-juggling, see BINAS, 1992).

II. On School Chemistry
   3. What you breath is no two O—O's, no sticks and balls.
   4. What exactly happens with all those descriptions and symbols? I want to see it!
   5. Not that we don't believe the authors but we just can not imagine what it is.

6. Hydrogen bridges, dipoles? Nobody gives clear answers to these questions.
7. Plugging numbers in the calculator. Without ever asking ourselves about why and what for.
8. Extensive and complicated calculations. It is being taught like maths. The major part is using algorithms solving equations. Solving equations without really understanding why. It is too abstract to be challenging. It is much too theoretical.
9. The fun part of chemistry is the labs. Believing the attraction is in doing experiments. Experimenting in a lab, wearing a labcoat and holding test tubes, seems to be more fun. If I would choose chemistry, I would want to work in a lab.

III. On Chemistry As a Profession

10. It's image doesn't fit. Negative image. What use is it to become a chemist?
11. Believing chemistry is less important to know than, for example, economics.
12. A person in a white coat working in a lab. The stereotype of an absent-minded scholar at a lab-bench with bubbling flasks and steaming erlenmeyers.
13. Becoming a chemist gives many different job options: in research, as well as in business, planning, management.
14. Unaware of the many other job prospects (*other than in research*) for chemists and chemical engineers.

IV. About Computers In Chemistry

15. Computing? Modeling? Never heard of.
16. This provides real spatial insight/understanding. It gives a clear view of molecules and structures.
17. Chemistry becomes visual: isomerism, distances, angles; charges and reactions become clear.
18. A fun program and broadly applicable. For example on problems concerning conformations of 1,2 di-chloroethane.
19. So, chemistry is not restricted to knowledge in books.
20. I am not a computer freak.
21. Too much computing. This is also just theory.
22. The application of all this wasn't clear to me.

V. On This Project

23. A fantastic experience! Would not have missed this for the world!
24. Never thougth the things we learn are actually used in real life, and on such a big scale.
25. On DSM Nylon-6 carpets recycling process: never realized the great importance and use of such a simple reaction!
26. For the first time I understood that many things are yet unknown. The grand scale of the processes in a chemical plant!

VI. Student's Suggestions

27. Develop genuine working collaborations of research chemists and chemistry teachers to incorporate in schools "Todays Chemistry in Research and Practice."
28. Why not make chemistry more attractive by updating instruction materials (books, videos), computer facilities, and laboratory equipment?
29. Present projects like this one to students in lower grades who have yet to decide on their senior high school program.

VII. Student's General Observations

30. Our generation is the generation of the ZAP culture who cannot spend a long period of time on any one topic.
31. High-school students in chemistry courses do not plan to continue in chemistry. Some are opting for college degree programs requiring chemistry.
32. Desiring further education/training applying chemistry in concert with other disciplines.

VIII. Teacher's Observations

33. Group A completed the first assignment in half the time scheduled! Even those, who in their essays had stressed the point of not being computer freaks (20 and 21).
34. The students easily mastered the simulations. They were distracted quickly, obviously attracted by internet and chatbox (group A).

35. The black-box approach worked very well. Apparently, the students were not bothered by not knowing the origin of the various models and the basic ideas used.
36. In some instances however, the chemical information provided was rather inadequate. They didn't gain much from the explanations given.
37. The high school handbook (BINAS, 1992) provides distances and angles needed for calculations, but it does not "come alive."
38. A chemistry teacher is someone explaining experiments that noone actually saw.
39. The English language was no problem for them.
40. The DSM industrial site was a revelation!

DISCUSSION

Fair minded: Clearly, what we hoped for was provided. It is immediately clear that *today's chemistry is not conveyed* (1–9). Obviously, the students concluded that today's chemistry is not what is being taught in school. It is being taught like maths (2 and 8), it is too abstract, and what exactly happens with all those descriptions and symbols? I want to see it (4). It amounts to plugging numbers in calculators (7) and number-juggling (2). Hydrogen bridges, dipoles? What you breathe is no two O—O's. They can just not imagine what chemistry is about (3, 5, and 6).

To them, chemistry in schools is experienced as just laboratory experiments, playing around with some small stuff (1). It seems that a chemist is just a person in a white coat at a lab-bench with bubbling flasks and steaming erlenmeyers (12). What use is it to become a chemist (10 and 14)? Chemistry is less important to know than (for example) economics (11). Interestingly, some students are well aware of the many different other job options for chemists (13). However, that does not lure them to decide to go for a chemistry degree (31 and 32).

It's fun and easier to understand: The hands-on introduction to computer molecular modeling reveals how the students grasp immediately the chemical meaning by recognizing *visuospatially* the crucial role of molecular shape, form and symmetry (16–19). With an "Aha" sensation, they suddenly understood the meaning of prefixes, symbols, and numbers that they had been taught in school (see Fig. 2 and 3). Some similar findings, interestingly, are reported in "A Student Evaluation of Molecular Modeling in First Year College Chemistry" (Ealy, 1999), a paper published during the preparation of our report. As it turns out, students both in our group (B-1 and B-2) as well as in Ealy's study judged the Spartan program a fun program, enjoyable, easy to use (18), and affording better understanding of chemistry. But some other students, as also in some of Ealy's study, were clearly not enthused by using computer molecular modeling : "I am not a computer freak" (20), and " Too much computing. This is also just theory" (21).

On schoolbook chemistry: In the confrontation project, they became aware for the first time of the many things yet unknown (26). Never had an inkling, that the things they learn are actually used in real life (24). So, chemistry is not restricted to knowledge in books (19). All these pronouncements, really, are underscoring the criticism recently voiced in the American Chemical Society, that too many teachers are teaching science as if it were something out of a book (Ware, S., cited by Deutsch, 1999). A statement affirmed, albeit unknowingly, by one of the teachers: "A chemistry teacher is someone explaining experiments that noone actually saw" (38). The students, voluntarily, offered some suggestions for change. One of which aims for genuine working collaborations of *research chemists* and *chemistry teachers to incorporate* in schools *today's chemistry* in research and in practice (27).

Basic skills: Group A completed the first of the two big assignments in half the time scheduled (33), even those who in their essays had stressed the point of *not* being computer freaks (20). Our observations in all three project groups demonstrate the ease with which these youngsters *perform* the molecular modeling experiments at the computer. These findings clearly demonstrate experience acquired in out-of-school learning, in learning controlled by PC games and the many new other uses of PC technology. It may be true that PC games, video or TV do not teach the 'correct' things. The point is that they *do* teach (Smith, 1993). Our students clearly demonstrated at the computer an additional *basic skill*, besides reading and writing, which is founded on a highly developed visuospatial talent (Gardner, 1993, 1999; Habraken, 2000).

Hands-on chemistry: The erosion of hands-on chemistry in schools is of much concern. But today, apparently, students consider both working in the *laboratory* as well as working at the *computer screen as* *hands-on* experience (Ealy, 1999). Our students suggested making chemistry more attractive by updating both computer facilities and laboratory equipment (28). Using calculators on the other hand, we observed, is not considered to be hands-on experimenting.

WHAT NEXT

This has been essentially an exploratory study. Contrary to much research aiming for *improving* chemical education this study aimed at *exploring*, from the student's out-of-school point of view, *neglected factors* controlling the continuing deflection from chemistry. First of all, the results obtained clearly demonstrate *school chemistry's failure* to convey today's chemistry in research and in industry. School chemistry is too abstract, it is being taught like maths. Secondly, and at the *computer screen*, the students demonstrated their skills in *performing* the assigned molecular modeling experiments. Moreover, chemistry at the computer screen was considered to be fun, making understanding chemistry much easier.

Concurrently, both the *failure* to convey today's chemistry to our young, "it's like maths," *and the fun* and the ease with which they performed the molecular modeling experiments underlines dominance in pictorial thinking. Children now are growing up acquiring highly developed visuospatial talents and skills, *and* chemistry, albeit taken for granted, is a science highly dependent upon visuospatial intelligence (Davies *et al.*, 1990; Rushkoff, 1997; Luisi and Thomas, 1990; Gardner, 1993, 1999; Habraken, 1996, 2000; Smith, 1993).

What is important *today* is to *integrate* into chemistry's teaching today's student's visuospatial skills and talents together with the teaching of 'reading' and 'writing' in formal pictures and computer models *in* today's chemistry. Finally, this study demonstrates the impact of the crucial feature that all *participants*, the volunteer students, the teacher, the chemistry researcher are all *collaborators* as well as *subjects*.

The young are not just the students–they are also the teachers!

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