CHEMISTRY EDUCATION:
RESEARCH AND PRACTICE IN EUROPE
2001, Vol. 2, No. 3, pp. 227-239

RESEARCH REPORT
Methods and issues of teaching and learning

Hans-Dieter BARKE and Temechegn ENGIDA
University of Muenster, Institute for Didactics of Chemistry

STRUCTURAL CHEMISTRY AND SPATIAL ABILITY IN DIFFERENT CULTURES

Received 23 January 2001; revised 22 June2001; accepted 4 July 2001

ABSTRACT: In chemistry, the importance of structure of matter cannot be underestimated. It has always been a tradition in organic chemistry to use the stick-and-ball model of molecular structure, to discuss isomers or to derive structural formulas. Unfortunately, this structure-oriented approach is not common in teaching inorganic chemistry at secondary schools at least in Germany: Although metals, sulfur, sulfides, oxides or chlorides are mostly taken as solid substances, in school lessons it is not common to have sphere packings or crystal lattices as structural models of these inorganic solids. On the other hand, true understanding of structures in chemistry requires a sufficient level of spatial ability. Accordingly, this research investigated spatial abilities not only of German students at grades 7 – 12 of secondary schools (ages 13 – 18 years), but also a comparable sample of African students in Addis Ababa. In each country, we took samples of two different school types and based our studies on three hypotheses dealing with cultural, grade (age) and sex differences. [*Chem. Educ. Res. Pract. Eur.*: 2001, *2*, 227-239]

KEY WORDS: *structural chemistry; chemical structure; crystal lattice; molecular structure; chemical symbols; imagination; spatial ability; spatial ability test; sex differences; cultural differences*

INTRODUCTION

"*Imagination is more important than knowledge*". These words of Albert Einstein illustrate our point of view very precisely: knowledge alone is not sufficient in science or chemical education; memorizing formulas and chemical equations should not be the only goal of chemistry lessons. What seems more important is the imagination that we develop according to the structure of matter, to the structure of crystal lattices and molecules.

However, it is not easy to get images with regard to Einstein's results. He developed theories from which we cannot really form mental pictures. Knowledge about electrons and descriptions of chemical bonding also seem difficult to imagine at least for schoolboys and girls: Are electrons particles and moving on shells, or have they wave properties, or both? Because of such difficulties, it is better to work on the base of Dalton's atomic model and to form mental images of atoms and ions as full spheres, to visualize crystal structures in terms of sphere packings or crystal lattice models, to imagine molecular structures with the help of ball-and-stick or full-sphere models. If high school, students grasp these ideas, they will build up their cognitive abilities in a better way than without any structural model.

Later, after getting familiar with main structures by using sphere models, students may look "into the spheres" and learn about the nucleus and electron shells – but there is nearly no way to visualize these aspects. Therefore, high-school students should study structural chemistry on the base of Dalton’s atomic theory, before discussing the ideas of nucleus and electrons. We will first give some theoretical considerations, then we present the idea of spatial ability and the Spatial Ability Test, and finally describe and discuss empirical research in this area.

FORMULAS AND STRUCTURAL BUILDING UNITS

Having first all the signs and icons from the alchemists of the middle ages, the historical development of modern chemical symbols started with Dalton's atomic model and Berzelius' proposals to use letters. Liebig and many other scientists of the 19th century took both ideas and derived empirical formulas, by comparing volumes of gases or masses of substances with involved atomic masses. These formulas were very useful to show the composition of substances, but could not give any idea about their structures. Gerhardt and Laurent later discussed the type theory: with the hydrogen type, the water type and the ammonia type, they gave us temporary images of some structures. Kekulé developed the valancy concept, proposed a lot of molecular structures, including that of the benzene molecule, and - with his valancy concept – provided us with many structural images of most organic molecules.

The logical way of scientific discussions during the 19th century was:

1. phenomena (properties of substances, masses and volumes);
2. empirical and molecular formulas;
3. structural imaginations and structural formulas.

In Germany, teachers usually follow this historical way of presenting chemical formulas. But this way is a very difficult one for students at the beginning level of chemistry in high schools (age of about 14 years): The process of deriving formulas from phenomena involoving masses and volumes is very abstract, and only a few students successfully follow the calculations according to comparisons of empirical and atomic masses. By his researches, Schmidt (1984) verified a lot of difficulties that high-school students have with this kind of stochiometric calculations.

At the beginning of the 20th century, Max von Laue, and father and son Bragg realized the first steps in finding the crystal structures of many substances by early methods of X-ray analysis. They even proposed the unit cell as the smallest unit of a crystal structure, and pointed out that the idea of the molecule makes no sense for salt structures like sodium chloride (Barke, 1990).

Today we have more sophisticated methods of X-ray analysis and know many crystal structures or unit cells. Scientists mostly visualize them by means of computers in a three dimensional way or even build structural models like sphere packings or spatial lattices. So there is a big chance to discuss these models of structure of matter and to derive formulas on the basis of them: Imagination is more important than knowledge! Students are able to develop structural images in their mind, and with these images they combine the knowledge of formulas. Table 1 summarizes this idea, while a brief description of the three steps follows:

TABLE 1. *Structural imaginations - mediator between phenomena and chemical symbols.*

Phenomena	substances and their properties	chemical reaction
	↓	↓
Structural Imagination	structural models of substances, connections to properties	structural models of substances before and after the reaction
	↓	↓
Chemical Symbols	structural formulas, symbols of the smallest unit of the structure	structural formulas in chemical equations, chemical equations

1. Phenomena: Investigating phenomena in nature or in the laboratory, showing substances and their properties, conducting experiments to show chemical reactions, offering students their own experiences by doing laboratory exercises.

2. Structural Imagination: Taking structural models to show the structure of the substances involved before and after reactions, offering students the opportunity to built their own experiences, by building structural models, developing structural images, and by handling these models.

3. Chemical Symbols: Deriving formulas from demonstrated or self-built models, in order to give students the idea that formulas are shorthand forms of structural models or of building units of the structure of molecules or unit cells.

In organic chemistry, most teachers agree to use molecular models and follow the three steps of Table 1: After showing new substances, they might demonstrate stick-and-ball models of the molecular structures and derive structural formulas. In cases where molecules are involved we agree: structural models and structural formulas show the smallest units of the substance.

The three steps of Table 1 are hardly followed in the inorganic part of high school chemistry, at least in Germany: Students know formulas like NaCl, $CaCl_2$ or Al_2O_3, but they have no mental pictures of the structures of these substances. They hardly even know about any crystal structure. They further have no idea about the building blocks of these crystal structures, because unit cells are usually not part of high-school curricula in Germany.

If we accept that formulas represent the building blocks of substances, like the formula C_6H_6 for a benzene molecule (no one will shorten this formula to C_1H_1 or CH), then we have to evaluate our chemistry curricula in the direction of introducing unit cells for crystal structures. We can teach high-school students the principles of X-ray analysis, using laser beam experiments (Barke, 1990); we can develop sphere packings or crystal lattice models (Barke, 1997; Sauermann & Barke, 1997); we can identify the unit cell with the help of cutting sphere packings (Barke, 1996); and we can derive formulas from unit cells (Barke & Wirbs, 2000).

Let us take an example. From the sphere packing model of the sodium chloride structure, we find the well-known unit cell. From the unit cell, we derive the formula $(Na^+)_4(Cl^-)_4$ or Na_4Cl_4. If necessary, we can shorten these formulas to $(Na^+)_1(Cl^-)_1$ or Na_1Cl_1 or NaCl. Figure 1 shows this idea.

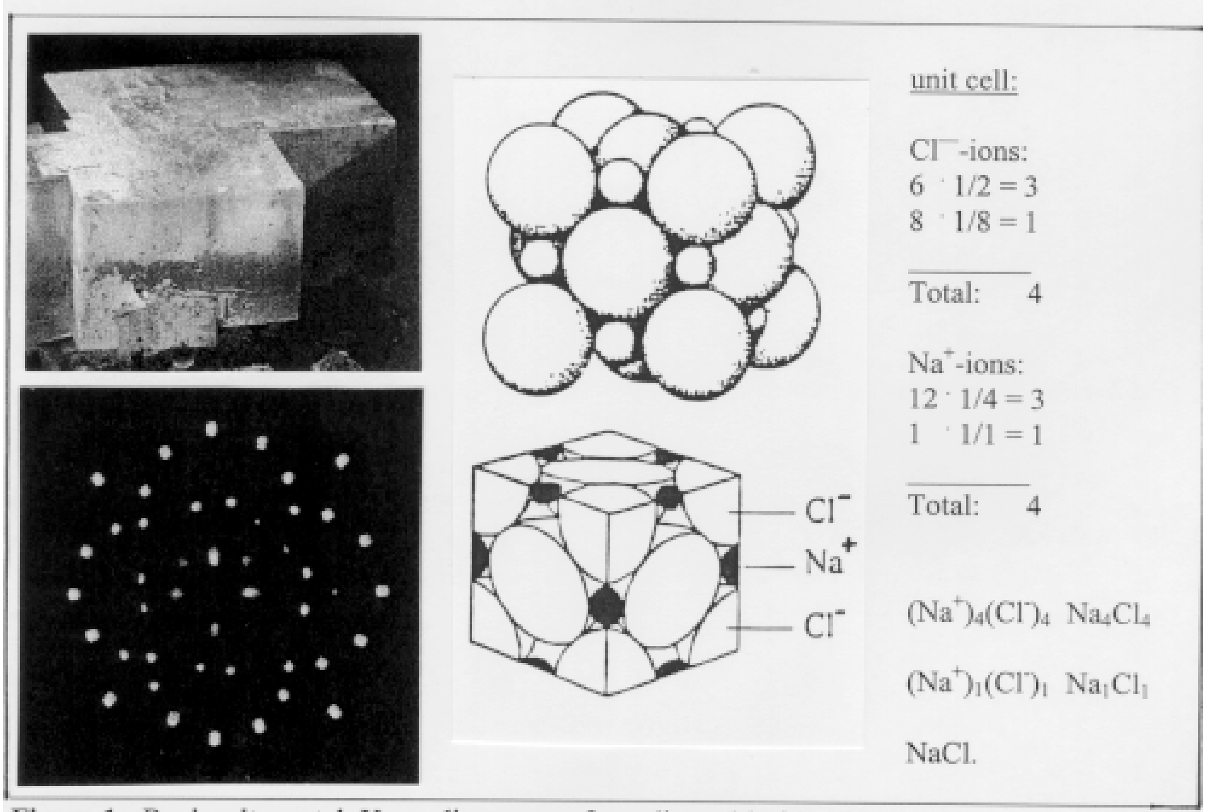


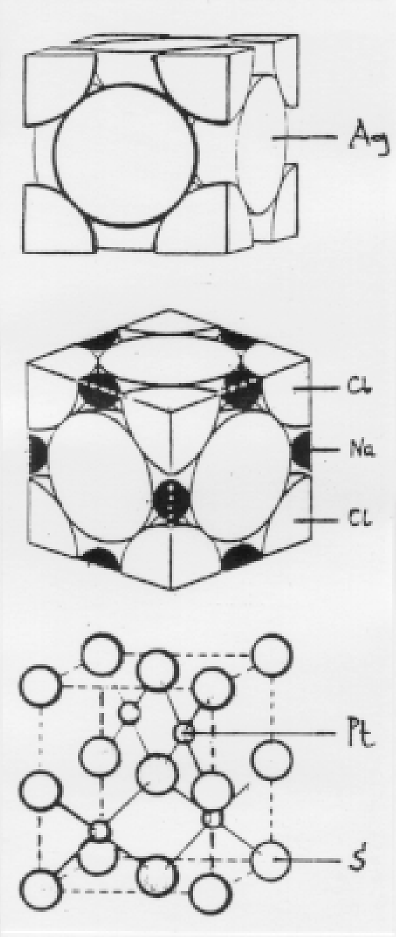
Figure 1: Rock salt crystal, X-ray diagramm of a sodium chloride crystal, structural models, unit cell and chemical symbols of the NaCl-structure

Working in this way, students should be able to generalize that: (1) molecules are the building units of molecular substances and are represented by formulas; and (2) unit cells are the building blocks or structural units of crystals, the contents of which are represented by formulas. Students would have mental pictures of both, molecular *and* crystal structures.

The major question at this point is: At what age will students have sufficient spatial ability to recognize the spatial structures of molecules and crystal lattices, especially of unit cells like that of the sodium chloride structure? To answer this question, we review the relevant literature, and discuss the Spatial Ability Test that reflects the nature of chemical structures.

SPATIAL ABILITY AND STRUCTURAL CHEMISTRY

Spatial ability is one of the primary abilities or *the* primary ability of intelligence (Thurstone, 1939). The space factor of intelligence can be described by two (or three) subfactors, named "spatial relations" and "visualisation" (Rost, 1977). Working with structural models in chemistry, we are in better position to recognize the subfactor "spatial relations", by recognizing for instance the three-dimensional relations in two-dimensional drawings or pictures of chemical structures (see Figures 1 and 2). The significance of spatial ability with regard to various school subjects and to many professions has been mentioned in the literature (Rost, 1977; Barke 1993). In addition, Coleman and Gotch (1998) have pointed out that "there is a strong indication that spatial skills are related to science achievement".



This unit cell describes the structure of a siver crystal.

1. How many Ag-1/8-spheres does the unit cell contain ? (8)
2. How many Ag-1/2-spheres does the unit cell contain ? (6)

This unit cell describes the structure of a sodium chloride crystal.

3. How many Cl-spheres does the unit cell contain, if all fractuional parts are added together? (4)
4. How many Na-1/4-spheres does the unit cell contain ? (12)
5. How many Na-spheres does the unit cell contain, if all parts are added together? Caution: Imagine that there is one full Na-sphere right in the middle of the cell. (4)

This model describes a section of a Platinum-Sulfur compound. If you cut in your mind all faces of the tetragonal body through the middle of the spheres, you imagine the unit cell.

6. How many S-1/2-spheres does this unit cell contain ? (2)
7. How many S-1/4-spheres does this unit cell contain ? (4)
8. How many full S-spheres does the unit cell contain, if all parts are linked together? Take care of the middle of the cell. (4)

Figure 2: Spatial Ability Test, items of task group 4 “Counting Unit cells”, correct answers in brackets

Spatial ability develops during childhood and youth. Barke (1993) found that around the age of 14 years, spatial ability is developed to a point that students interpret the two-dimensional drawings of cubes, tetrahedrons or octahedrons in a spatial way. But he also found that boys performed better than girls in this regard. Meyer (1994) cites 120 researches between 1932 and 1991 that show these sex differences in favour of the boys. The reasons are not investigated to satisfaction: Quaiser-Pohl (1998) discusses the influence of children's toys and the choice of different toys for boys and girls by parents. Many other researchers are claiming genetic influences (Linn & Peterson, 1985).

To get more information on spatial ability according to structures of molecules and sphere packings or unit cells, a structure-oriented test of spatial ability was developed (Barke, 1992). This test contains five groups of tasks listed in Table 2. Because of the significance of unit cells, the items of group "4. Counting Unit Cells" should be introduced. Figure 2 shows the items and correct answers, while Table 3 lists difficulty indices of boys and girls in the age of 14-16 years.

The preliminary results of this test are highly promising. Table 3 shows that most of the items are solved by 100% to 40% of all boys and girls – only the last three items are solved by

TABLE 2: *Groups of tasks and their corresponding instruction- and working-time in the Spatial Ability Test.*

Groups of Tasks	Instruction Time	Working Time
1. Cubes in Cube Packings	2:00 min	4:00 min
2. Spheres in Sphere Packings	2:00 min	7:00 min
3. Piles of Sphere Layers	2:00 min	7:00 min
4. Counting Unit Cells	2:00 min	7:00 min
5. Reflecting and Rotating Models	2:00 min	7:00 min
Total	10:00 min	32:00min

TABLE 3: *Difficulty indices for the Spatial Ability Subtest "Counting Unit Cells" (see Figure 2) Sample of 120 students taken from a Gymnasium near Hannover/Germany.*

Item	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Grade 8 (14 – 15 years)								
Boys	96	85	67	77	44	40	38	25
Girls	88	96	63	75	40	21	23	08
Grade 9 (15 – 16 years)								
Boys	100	92	78	84	69	35	35	31
Girls	86	83	59	55	55	31	42	24

fewer than 40% of the students. The results also tell us that, without any lecture on the unit cell, nearly half of the sample of students of the age 14 to 16 years were able to grasp the idea, through two warming-up exercises and could solve the test problems independently. This is a clear indication that these lectures would be successful in classes of grade 8 (age 14 – 15 years) or above.

Using the idea of unit cells and deriving formulas from them, students will be able to imagine spatial structures and will differentiate between crystal and molecular structures. When students are given models of unit cells of crystalline substances, they will develop mental images of crystal structures or infinite structures, and will differentiate these from finite structures like molecules. One of our next empirical researches will show the success in improving students' understanding especially of formulas of general chemistry, and will discuss the problems of the use of unit cells and other structural models in chemical education.

All results mentioned refer to students' spatial ability in German schools. Another question would be the extent of this ability in a non-western culture, such as Ethiopia. Accordingly, we administered the Amharic (Ethiopian official language) version of Barke's Spatial Ability Test in Ethiopia and also conducted additional research with comparable samples in Germany. Because there is no previous research work on spatial ability of Ethiopian children, we assumed that no differences exist between the two culture groups.

STUDENTS' SPATIAL ABILITY IN GERMANY AND ETHIOPIA

Because there are no other experiences with students' spatial ability in Ethiopia, we made a number of null-hypotheses with regard to: (a) differences in both cultures; (b) age development, (c) gender differences:

$H_0$1. There are no significant differences in spatial ability between the Ethiopian and German Secondary-school students.
$H_0$2. There are no significant differences in spatial ability of students of the various grade levels in each of the school types.
$H_0$3. There are no significant differences in spatial ability between boys and girls of the various grade levels in each of the school types.

After translating Barke's Spatial Ability Test into the Amharic language, and printing all test material, one of the authors (TE) went to Addis Ababa in spring 1999 and collected all

TABLE 4: *The Ehtio-German sample by school type, grade and gender. E1: Ethiopian Government Schools; E2: Ethiopian Non-Government Schools; G1: German Gymnasium Schools; G2: German Non-Gymnasium Schools; --: No data collected.*

Grade	Category	Ethiopia		Germany		Total
		E1	E2	G1	G2	
7	Total	99	137	106	--	342
	Boys	48	83	54	--	185
	Girls	51	54	52	--	157
8	Total	89	94	75	43	301
	Boys	44	52	38	30	164
	Girls	45	42	37	13	137
9	Total	60	47	87	122	316
	Boys	32	24	38	69	163
	Girls	28	23	49	53	153
10	Total	73	60	81	74	288
	Boys	45	39	37	38	159
	Girls	28	21	44	36	129
11	Total	41	38	51	21	151
	Boys	22	24	31	11	88
	Girls	19	14	20	10	63
12	Total	24	--	83	--	107
	Boys	11	--	52	--	63
	Girls	13	--	31	--	44
Grand	**Total**	386	376	483	260	**1505**
	Boys	202	222	250	148	**822**
	Girls	184	154	233	112	**683**

necessary data. He tested 763 students in Addis Ababa (Ethiopia), distributed over six consecutive grade levels from grade 7 (13-14 years old) to grade 12 (18-20 years old). In addition, 742 students were tested in Muenster and its surroundings (Germany). Because the samples (see Table 4) were taken from specific towns that were accessible to us, it cannot be claimed that they are random samples that represent the two countries adequately. However, within these towns schools and classes were selected randomly and a reasonable number of secondary school students participated.

Table 4 shows that the 1505 secondary school students (grades 7-12) were distributed in four different types of schools, two types in each country. In Germany, we have Gymnasium schools (G1) and Non-Gymnasium schools like Gesamtschule, Realschule and Hauptschule (G2). In Ethiopia, there are Government schools (E1) and Non-Government schools (E2). The majority of the Ethiopian children attend Government schools. The children of a few elitist and relatively rich people, however, go to Non-Government schools, since these families can afford to pay the school fees in private schools.

All students received the test handout plus an answer sheet and took about one teaching period (45 minutes) for the test. After being introduced to every group of tasks (total of 10 minutes), they answered on their answer sheets a number of multiple choice items, each with five alternatives answers (total of 32 minutes). Finally, the answer sheets were collected, the test brochures were taken for the next tests. See Table 2 and Figure 2 as an example for items in group 4 "Counting Unit Cells").

RESULTS

The data were analysed using SPSS for Windows and are available at the University of Muenster (Engida, 2000). Note that because the scores are not normally distributed, only a non-parametric test (Mann-Whitney-U Test) is used for testing significance of the differences for each of the null-hypotheses. Earlier investigations have proved the reliability and validity of the Spatial Ability Test (Barke, 1992).

Hypothesis H1

According to hypothesis H1, our sample of students from Muenster and Addis Ababa should have a statistically equal level of spatial ability, irrespective of school type. As shown in Figure 3, But the results, were quite different from our expectations. So the null-hypothesis has to be rejected. While the Gymnasium sample (G1) performed significantly better (p = .000) than both the Ethiopian samples E1 and E2, the Non-Gymnasium sample (G2) showed no significant differences over both E1 and E2. These results tell us that cultural factors have influences on spatial ability, in agreement with the findings of earlier research work that used other spatial ability tests (Hudson 1967, Berry 1971).

Following the discussion of Quaiser-Pohl (1998) with regard to the influence of toys, our observations prompted us to consider the availability of special toys during childhood. In Germany the parents can spend, irrespective of school type, money to buy mechanical toys or other materials for their children. The Western culture is available to both groups of children (G1 and G2) almost equally. This means that the children of the two school types have similar opportunities for childhood experiences. Such similarity should have influenced both groups to perform equally in the Spatial Test. The research, however, has shown that the two German samples differed significantly.

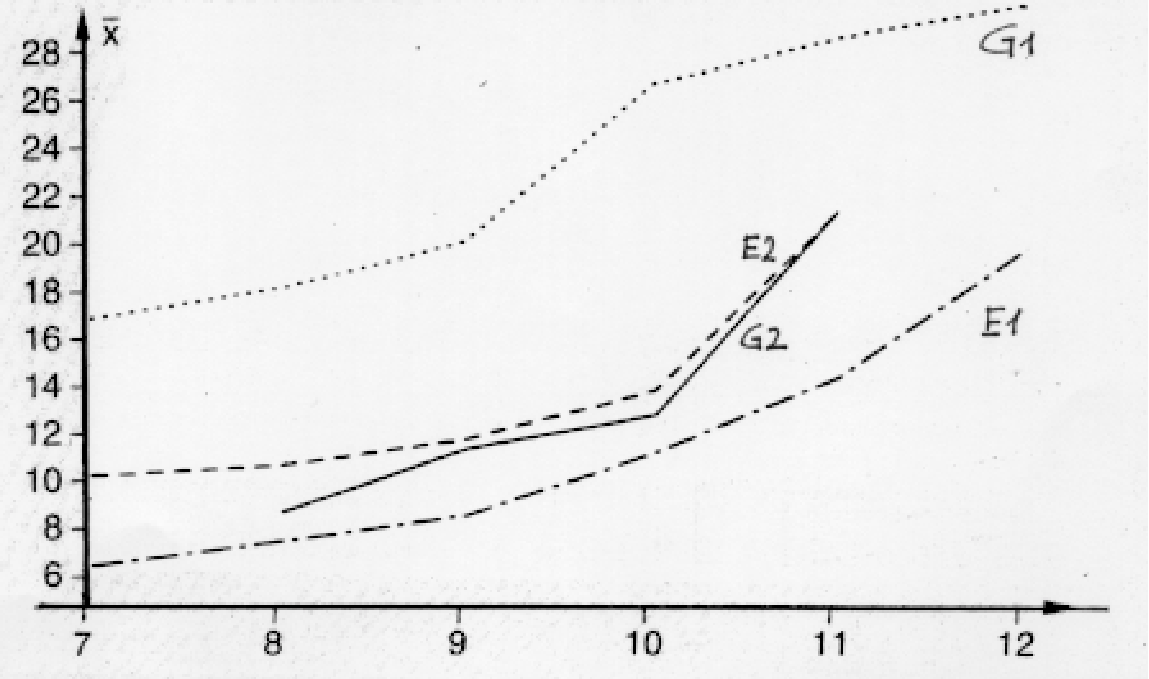


FIGURE 3: *Mean scores of spatial ability according to school type and grade: Gymnasien in Muenster (G1); Non-Gymnasien in Muenster (G2); Government schools (E1); Private schools (E2) in Addis Ababa. Maximum score 40.*

In Ethiopia the parents of the children in group E2 are relatively richer than the parents of those in group E1: the E2 parents have the financial capacity to offer their children the Western-type of playthings or toys, in addition to what the Ethiopian culture offers them. Such different opportunities to develop spatial abilities should have influenced the two groups to differ significantly. The research however confirmed that the difference between the two Ethiopian samples is very small as compared to the large differences between the German samples (see Figure 3). We also observe that the spatial ability of G1-students is significantly higher than not only E1 and E2, but also of G2 students. Moreover, the spatial abilities of the G2, E1 and E2 students seem more or less similar, despite the differences in culture and spatial experiences in childhood.

The above findings suggest that as far as secondary schools are concerned, childhood experiences and cultural factors play probably little part in explaining differences in spatial abilities. The differences seem to be attributed to school curricula. The G1 students use advanced curricula as compared to the other three school types. At all secondary levels (grade 7-12) the spatial ability demands of G1 students in mathematics, geography and science are more advanced than in G2, E1 or E2. Moreover, both school types in Ethiopia are supposed to use the same curricula in all subjects throughout the school years: the centrally developed secondary school curricula are expected to be implemented in all schools of Ethiopia (Engida, 1996). The results of this study thus suggest that the school curricula are probably the most influential factor in determining the differences in spatial ability of secondary school students! Future investigations will have to show how far the toys and school curricula influence the development of spatial ability.

Hypothesis H2

According to hypothesis H2, there should be no significant difference between two successive grades throughout the secondary school levels (grades 7 - 12) in each school type. As can be seen from Figures 3 and 4, there is a general development trend from grade 7 through grade 12 in each case. Such qualitative changes reflect the natural development of spatial ability in the age groups of 13 - 20. Barke observed earlier (1980, 1993) the same trend in German gymnasiums: another reference to the reliability and the validity of the test.

Contrary to the null-hypothesis H2, we observed statistically significant differences ($p < .05$) between two successive grades in some cases, hence the null-hypothesis H2 has to be rejected. However, the grade level at which a significant increase in spatial ability was observed is not the same for all school types: In G1 it is from grade 9 → 10, in G2 and E2 from 10 → 11, in E1 from 11 → 12. This means that, although the students of the above school types have the same number of years of educational background, significant differences between two successive grades appeared earlier in the Gymnasium schools, later in Non-Gymnasium and Non-Government schools, and very late in the Government schools (see Figures 3 and 4).

In order to suggest plausible explanations for the observed significant differences between some grades, we looked for spatial tasks in the curricula and in the most widely used textbooks of mathematics and science. We then found that whenever concepts that require spatial ability are provided at a given grade, the students develop their spatial ability significantly better than those of the lower level. In Germany, gymnasium curricula of mathematics, physics and chemistry at grade 9 offer many tasks that require spatial ability, and this provides a possible explanation for the fact that the major increase in this ability results from grade 9 → 10. In the other three school types, curricula may offer these tasks later in grade 10 or even in grade 11. This influence of curricula on spatial ability is a new hypothesis and has to be investigated through further research.

Hypothesis H3

This hypothesis deals with gender differences in spatial ability and assumes non-significant differences between boys and girls. Our investigation, however, shows that hypothesis H3 can neither be fully rejected nor accepted at the required level of significance ($p < .05$). Qualitatively speaking, there are two distinct trends in our results: big gender differences in favour of the boys in the German samples, and little or no difference in Ethiopian samples (Figure 4).

In every case whenever there is a difference, whatever the extent may be, the boys are ahead of the girls. Statistically speaking, the Ethiopian samples E1 and E2 showed significant gender differences in favour of the boys only at grade 7 ($p < .05$), but the German samples showed significant difference ($p < .05$) at most grades. The observed gender differences in the German samples are consistent with earlier findings (Barke, 1993; Bodner et al., 1986; Caplan et al., 1985; Colemann et al., 1998; Linn et al., 1985; Macoby et al., 1974; Meyer, 1994; Prybil et al., 1987).

All explanations of gender differences in terms of evolutionary, genetic or hormonal influences are just hypotheses (Kimura, 1992; Quaiser-Pohl, 1998). Our attempt to identify the factors responsible for gender differences in the German sample and for no differences in the Ethiopian sample is in its infancy – but all considerations are first speculations and have to be proved by future empirical research.

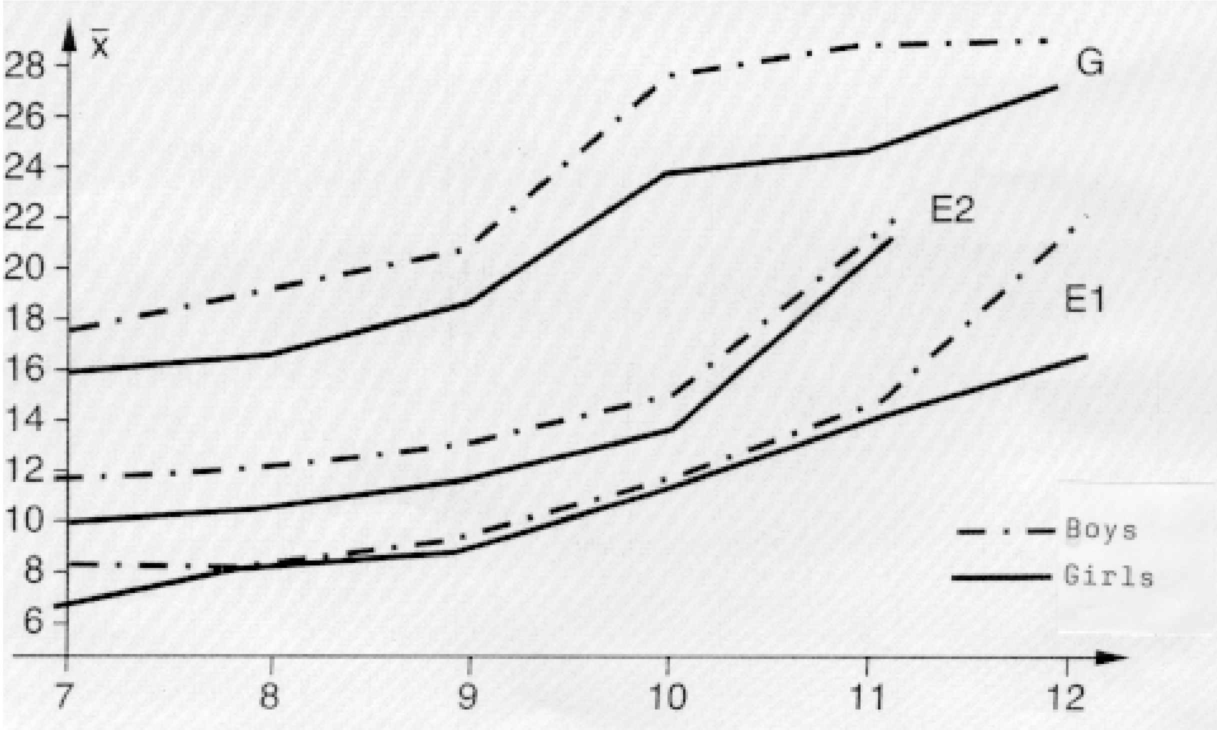


FIGURE 4: *Mean scores of spatial ability according to school type, grade and sex. Gymnasien in Muenster (G); Government schools (E1); Private schools (E2) in Addis Ababa. Maximum score 40.*

The German society, as other western societies, has the means to provide children with a variety of toys. On the basis of findings by Quaiser-Pohl (1998), there might be some differentiation between boys and girls, with regard to the kind of playthings they receive from their parent. Boys often get more technical toys, building sets for ships, and cars or other 'action' toys, while girls rather play more with puppets and other 'passive' toys (Quaiser-Pohl, 1998). This gives boys an advantage in developing their spatial ability, already during childhood.

The above expectations may also be valid for students of the Ethiopian group E2, whose parents have the money to bye toys for them. On this basis, it would be expected that gender differences are similar to those of the western cultures (Figure 4). On the other hand, the majority of the Ethiopian society is not capable of buying toys for their children. Both boys and girls play, for instance, by making differently shaped objects out of mud, although girls concentrate on constructing household objects. This might be an explanation for the same scores in the Spatial Ability Test from grade 8 through grade 11 (Figure 4). During this time, there are no differences in spatial experiences between boys and girls, so they perform in the same way with regard to spatial ability. In grade 12, however, the school curriculum involves the students in more tasks that require spatial ability, so they develop this ability in different dimensions. For proving these speculations, we have to do more research in the future.

CONCLUSION

Spatial ability is called *the* primary factor of intelligence and is not only important for good success in school subjects like mathematics and science, but also necessary for success in most professions. Figures 3 and 4 indicate the development of spatial ability in relation to the age of boys and girls. They especially show the increase of this ability from grade 9 → 10 for G1-students, from grade 10 → 11 for G2- and E2-students, from grade 11 → 12 for E1-students.

Our attempt to explain these jumps is based on spatial ability demands in curricula of mathematics or science: Whenever special tasks or objects require spatial ability, students start to exercise and to develop that ability. If we try to exercise spatial ability earlier than usual, children or students will develop their spatial ability in earlier ages than usual. In school subjects like mathematics, science or geography, teachers should consider this possibility.

In chemistry, we suggest the use of structural models as early as possible. According to earlier researches, grade 7 is not suitable, it would be more successful to start in grade 8. But having the simple idea that matter is made up of small particles, we can start to explain the structure of metals by building sphere packings. (Metals are involved in most curricula as the first solids for reactions with sulfur, oxygen or chlorine.) We can try to find the coordination number, to extract the elementary cube out of the closest cubic packing, to work with the unit cell (Figure 1).

Our research shows that boys and girls in grade 8 are able to make calculations with unit cells (Figure 2 and Table 3). Later on, the lectures may introduce alloys and may discuss sphere packings built of two kinds of spheres: (a) Gold-copper-alloys are shown with the help of packing of spheres of the same size but different colour; these alloys form even special structures like Cu_3Au_1 and Cu_1Au_1 (Barke & Wirbs, 2000). Iron-carbon-alloys (steel) are discussed on the basis of packing of spheres of different sizes, i.e. carbon atoms that occupy octahedron holes of the cubic packing of iron atoms. Later on, salt structures and packing of ions are interpreted with suitable sphere packing. Finally, the structures of molecules should be visualized with the aid of the well-known ball-and-stick models or other molecular models.

Working with structural models will not only help students to develop their spatial ability earlier than usual, it would also lead to a better understanding of chemistry, especially to understanding the meaning of formulas and equations (Table 1). If students are asked to build structural models by themselves, they will develop both abilities: good chemical understanding and spatial ability. Especially girls may have an additional training in spatial ability and thus come closer to the scores of boys. Further research in this area is certainly necessary.

CORRESPONDENCE: *(a) Hans-Dieter BAKE, Institute for Didactics of Chemistry, Fliednerstr. 21, 48149 Muenster, Germany; Fax: ++49 251 83 38313; email: barke@uni-muenster.de*
(b) Temechegn ENGIDA, Addis Ababa University, PO Box 150090, Addis Ababa, Ethiopia.

REFERENCES

Barke, H.-D. (1980). *Raumvorstellung im naturwissenschaftlichen Unterricht* (Spatial ability in science education). MNU 33, 129-133.

Barke, H.-D. (1990). Lauediagramme fuer den Chemieunterricht (X-ray-diagrams in chemical education). *Praxis Chemie, 39*, Heft 6, 13-19.

Barke, H.-D., Kuhrke, R. (1992). *Einfuehrung in die Chemie. Von Alltagsvorstellungen zu ersten Strukturvorstellungen* (Introduction in chemistry. From every-day-life phenomena to first structural imagination). Frankfurt: Verlag Lang.

Barke, H.-D. (1993). Chemical education and spatial ability. *Journal of Chemical Education*, *70*, 968.

Barke, H.-D. (1996). Elementarzelle - Stiefkind neben dem Molekuel? (Unit cell - stepchild beside the molecule?). *CHEMKON, 3*, Heft 1, 19-24.

Barke, H.-D. (1997). The structure-oriented approach: Demonstrated by interdisciplinary teaching of spatial abilities. In: Graeber, W., Bolte, C.: *Scientific Literacy*. Kiel: IPN.

Barke, H.-D., Wirbs, H. (2000). Chemische Symbole fuer kleinste Struktureinheiten (Chemical symbols for structural building units). *Praxis Chemie, 49*, Heft 2, 2-8.

Berry, J.W. (1971). Ecological and cultural factors in spatial perceptual development. *Canadian Journal of Behavioral Science, 3*, 324-329.

Bodner, G.M., McMillen, T.L.B. (1986). Cognitive restructuring as an early stage in problem solving. *Journal of Research in Science Teaching, 23*, 727-738.

Caplan, P.J., MacPherson, G.M., Tobin, P. (1985). Do sex-related differences in spatial abilities exist? A multilevel critique with new data. *American Psychologist, 40*, 786.

Carter, C.S., LaRussa, M.A., Bodner, G.M. (1987). A study of two measures of spatial ability as predictors of success in different levels of general chemistry. *Journal of Research in Science Teaching, 24*, 645-657.

Coleman, S.L., Gotch, A.J. (1998). Spatial perception skills of chemistry students. *Journal of Chemical Education, 75*, 206-209.

Engida, T., Mengesha, S., Yigzaw, Y. (1996). A survey study on Ethiopian high school chemistry: contents of the textbooks. *Solutions: A Biannual Newsletter of the Chemical Society of Ethiopia, 4* (1) 2-12.

Engida, T. (2000). *Structural chemistry and spatial ability in chemical education. a case of selected German and Ethiopian schools* (Dissertation). Muenster, Germany: University of Muenster.

Hudson, W. (1967). The study of the problem of pictorial perception among unacculturated groups. *International Journal of Psychology, 2*, 89-102.

Kimura, D. (1992). Weibliches und maennliches Gehirn (Female and male brain). *Spektrum der Wissenschaft*, 11/1992, 104-116.

Linn, M.C., Peterson, A.C. (1985). Emergence and characterization of sex differences in spatial ability: A meta-analysis. *Child Development, 56*, 1479-1492.

Macoby, E.E., Jacklin, C.N. (1974). *The psychology of sex differences*. Stanford: Stanford University Press.

Maier, P.H. (1994). Raumliches Vorstellungsvermoegen: Komponenten, geschlechtsspezifische Differenzen, Relevanz, Entwicklung und Realisierung in der Realschule (Spatial ability: Components, sex-related differences, significance, development and realisation in the middle school). Frankfurt: Verlag Lang.

Pribyl, J.R., Bodner, G.M. (1987). Spatial ability and its role in organic chemistry: A study of four organic courses. *Journal of Research in Science Teaching, 24*, 229-240.

Quaiser-Pohl, C. (1998). Die Faehigkeit zur raeumlichen Vorstellung (The ability of spatial imagination) (Dissertation). Muenster, Germany: University of Muenster.

Rost, D. (1977). *Raumvorstellung. Psychologische und paedagogische Aspekte* (Spatial ability. Psychological and pedagogical aspects). Weinheim: Verlag Beltz.

Sauermann, D., Barke, H.-D. (1997). *Chemie für Quereinsteiger. Band 2: Strukturen der Metalle und Legierungen* (Chemistry for cross-entries. Volume 2: Structures of metals and alloys). Muenster: Verlag Schueling.

Schmidt, H.J. (1984). How pupils think - Empirical studies on pupil's understanding of simple quantitative relationships in chemistry. *School Science Review, 66*, 156.

Thurstone, L.L. (1938). *Primary mental abilities*. Psychometric Monographs 1.