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Slovenian Pre-Service Teachers' Conceptions about Liquid Crystals

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A total of 448 first-year university students participated in the study at the beginning of the academic year 2009/10. A paper-pencil liquid crystal questionnaire (LCQ) comprising 20 items was used to evaluate students' general conceptions related to liquid crystals, their properties and to the state of matter in general. The results show that 2/3 of students are not familiar with liquid crystals at all, and the conceptions about liquid crystals of the remaining 1/3 of students are very weak. Students achieved on average only 1.5 points (19 % success) out of 8 on the items testing their conception about liquid crystals. The students' achievements in the LCQ depend on their gender, their self-assessed knowledge on liquid crystals and on their field of study. Based on the results of the LCQ, learning units were developed to stimulate students' knowledge development about liquid crystals. The learning units in which students learn about liquid crystals synthesis (chemical aspects) and properties (physical aspects) were put in the framework of everyday life.

Keywords: *Liquid Crystals, Liquid Crystals Properties, Pre-Service Teachers' Conceptions*

INTRODUCTION

Liquid crystals (LC) are omnipresent in research and daily life. Many people are aware that liquid crystals are present in displays, phones, laptops, etc. But they rarely know that liquid crystals also exist in natural systems such as biological membranes, cell membranes, DNA, silk and even in some skeletons of bugs (Brown et al., 1983; Vilfan et al., 2002; Wright 1973). Technologically they are used in the systems where fast response is needed.

Since the topic is very interesting and it connects chemistry, physics and in some aspects also biology, it seems a suitable content for interdisciplinary integration of the natural science subjects. It enables study and discussions from different points of view, which leads to knowledge with understanding. This is especially important because of the enormous fragmentation of school knowledge, where students have many difficulties in connecting the content into a meaningful whole (Bulte et al., 2004, Flowers et al., 1999).

However, despite the fact that liquid crystals are quite common, informal discussions with students show that they have very limited knowledge about them. Indeed, it is known that young people in Europe are becoming increasingly uninterested in science at school and are not interested in studying science at the university level (Dolinšek et al., 2006). The main problem is that the school chemistry and physics usually have little in common with students' experiences from everyday life. But students' interest in and attitudes towards science are crucial aspects of science education. They help motivate students and make the educational process more relevant (Colletta & Chiapetta, 1994). Teachers are an integral part in the process of making students motivated. When teachers consider students' interests (intrinsic motivation) they will not only motivate students, but will also lead them on the way to scientific literacy. However, teachers at the in-service teachers' training courses agreed that liquid crystals are a

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State of the literature

- Researchers in science education describe the prevalence of the liquid crystals and the need for including them into the lectures and laboratories on the faculty. However, we would like to present them also to secondary school students.
- When designing a teaching module one has to take into account the pre-knowledge of students. Informally obtained knowledge about liquid crystals helps to design the teaching module about liquid crystals.
- Teachers need to be aware of world they live in and develop the knowledge about liquid crystals.

Contribution of this paper to the literature

- The study shows that, despite the fact that liquid crystals are common in everyday life, students have a very limited knowledge about them.
- This study explicates the influence of gender, self-assessment, motivation and field of study on pre-service teacher conceptions about liquid crystals.
- The paper raises several issues for educators in designing liquid crystal teaching modules with the purpose of awareness and understanding of liquid crystals.

very interesting topic. But presenting them to students during the physics or chemistry lessons is a difficult task for most of the teachers as they most of them describe their knowledge about liquid crystals as negligible.

Researches (Anderman & Young, 1994) show that gender differences in motivation for learning science in the primary school are linked to the performance on tests of knowledge in science (extrinsic motivation). It was also found that female pupils show less interest in science. Female students find science boring, especially because they often have to learn many things by heart. Simpson and Oliver (1990) report that female secondary school students have low self-esteem and lower levels of confidence for proving themselves in science. On the other hand, Meece and Jones (1996) did not confirm these results, they found no difference between female and male secondary school students in connection with interest in learning science, and stressed that the influence of motivation on the gender is much more complex than some researchers are trying to show. If we go up the education vertical, we find that, although the number of women enrolled in science has been constantly increasing in the past few decades, there are still significant differences detected between genders as regards the interest in physics, which is evidenced by a higher number of male than female students in the study programs of Physics (Zhu, 2007).

A possible way to motivate students for learning and studying science is to include contexts in which chemical and physical concepts are connected to the daily life of students. These context-based approaches aim to bring the students' learning closer to their own experiences and thus make the learning of science more meaningful (Bulte et al., 2004). One possibility to apply context based science learning is by including contents which are related to real life problems and are also the subject of scientific research (Gerlič, 1984). Students are interested in new technology but they do not have enough knowledge to understand it. If teachers want to introduce such contents into the science classes they have to be familiar with the content and know how this content is related to the competences in the curriculum (Lipovnik, 2008).

To stimulate the interest in studying physics, an approach to teaching physics was suggested (Häussler & Hoffmann, 2002) that: (1) provides opportunities to marvel, (2) links content to prior experiences for both boys and girls, (3) provides first-hand experiences, (4) encourages discussions and reflections on the social importance of physics, (5) connects physics with applications, (6) shows physics in relation to the human body, and (7) demonstrates the benefit and use of treating physics quantitatively. At the same time, the authors conclude that male students are more interested in the technical use of physical concepts, while the knowledge in conjunction with the human body shows no difference in interest between genders (Häussler & Hoffmann, 2002).

Liquid crystals enable the introduction of all seven of the above mentioned approaches to teaching physics and in addition enable interdisciplinary connection among the natural sciences and also mathematics.

Liquid crystals are organic substances, in which the liquid crystalline phase occurs between the solid (crystal) and liquid (isotropic) phase. Liquid crystals flow like liquids, however their optical and mechanical properties resemble the properties of the solid crystalline structures. There are two types of liquid crystals. Thermotropic liquid crystals are pure substances in which order appears due to temperature and sometimes due to pressure. In lyotropic liquid crystals, the appearance of the liquid crystalline phase depends on the concentration of liquid crystal in a solution.

We shall focus on the thermotropic liquid crystals only. An example of thermotropic liquid crystals is MBBA. MBBA is very interesting for teaching purposes, because it has a liquid crystalline phase at room temperature. Because of that it enables easy experimenting in the classroom. In addition it can also be synthesised in the school chemistry lab.

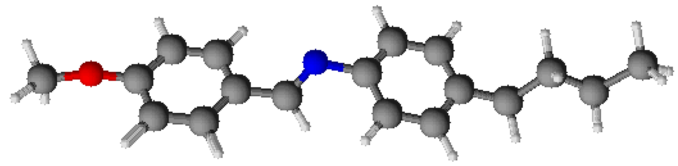

Figure 1. Molecule of MBBA (4-butyl-N-((4-methoxyphenyl)methylene)) liquid crystal

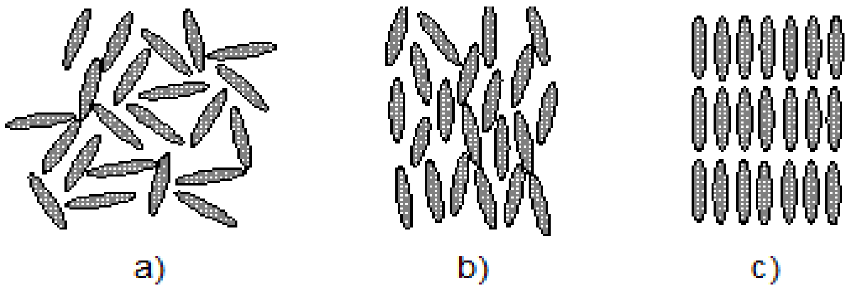

Figure 2. Different states of matter on molecular level: a) Isotropic liquid, b) nematic liquid crystalline phase, c) crystal.

Thermotropic liquid crystals are usually made of elongated molecules (Fig. 1) which contain a rigid core of a few benzene rings. At high enough temperatures liquid crystals are in the isotropic phase, where the arrangement of molecules regarding the molecular mass centres and the orientation of the long molecular axes is completely random (Fig. 2a). At lower temperatures, the molecules are oriented in a certain direction (Fig. 2b), however there is no order in the position of the molecular mass centres (Brown, 1983). This liquid crystalline phase is called nematic and it is most commonly used in application. At sufficiently low temperatures molecules are ordered in a crystal lattice (Fig. 2c), so in this case there exists a positional order of molecular mass centres as well. Intermolecular forces give rise to the orientational order of long molecular axes.

If the liquid crystal in the solid crystalline phase is heated it melts. The positional order of the molecular mass centres is destroyed, but the orientational order of the long molecular axes still persists. Due to the melting of the positional order the new phase is liquid-like, however the liquid is anisotropic because the order of the long molecular axes is still present. This phase, the nematic liquid crystalline phase, looks like an opaque liquid (see Fig. 3). If the temperature further increases, the phase transition from the anisotropic liquid crystal phase to the clear isotropic liquid phase appears. During this phase transition the orientational order of the long molecular axes is destroyed as well (Vilfan & Muševič, 2002).

Liquid crystals are a good example of connecting the teaching of physics and chemistry and the new research topic. Linkinvcg material properties to its structure is a useful approach when selecting appropriate topics which enable the learning of new concepts (Cussler et al., 2001). At the same time, knowing and understanding of different types of materials and their structures enables a design of new materials with the desired properties. The search for new "smart materials", i.e. materials whose mechanical, optical and electromagnetic properties can easily be changed by external fields, is very important for the progress of science and technology. Liquid crystals are an example of such "smart materials". Their crucial advantage is also in the fact that their mass production is very cheap. Upon their discovery they were characterized as not particularly useful new materials. However, nowadays liquid crystal displays (LCDs) are so common that most people are able to identify their existence (Waclawik, 2004; Vaupotič, 1996; de Gennes & Prost, 1993).

Purpose of the study and research questions

In order to introduce liquid crystals into the teaching of physics and chemistry, students' knowledge about liquid crystals was evaluated. Although students do not

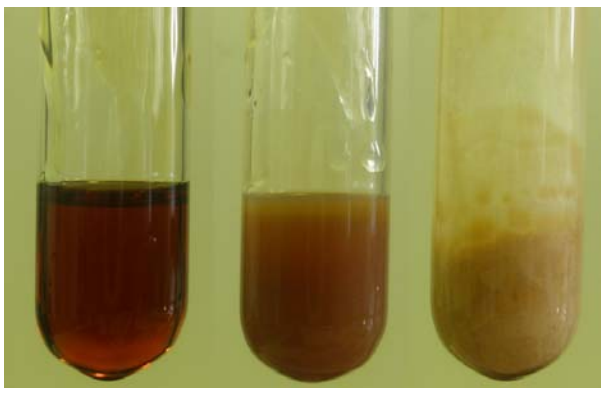

Figure 3. Liquid (1), liquid crystaline (2) and solid state (3) phase of MBBA

officially learn about liquid crystals in elementary or secondary school (no such content is directed by the national curriculums), it was expected that they gained some knowledge about them through the informal education. The influence of gender, self-assessment of the knowledge on liquid crystals, motivation for learning science and the field of students' study (e.g. chemistry, physics, biology, primary school teacher...) on the knowledge about liquid crystals was determined.

According to the reviewed literature and research problem the following research questions were stated:

- ✓ Do pre-service teachers on average achieve at least 50 % of points on LCQ?
- ✓ Do students who self-assessed their knowledge on liquid crystals as good achieve better results on LCQ than students who self-assessed their knowledge as negligible?
- ✓ Do male and female students achieve significantly different results on LCQ?
- ✓ Do pre-service science teachers obtain significantly better results on LCQ than pre-service teachers in other fields?
- ✓ Do students who are highly intrinsically or extrinsically motivated for learning science achieve significantly better results on LCQ?

METHODS

Participants

448 pre-service teachers, first year university students (9.6 % male, 90.4 % female), participated in the study. On average, the students were 19.2 years old (SD = 1.0 years). 15 % of students were studying chemistry or physics, 16.5 % other natural sciences (biology, home economics, computer science, mathematics or technology) and 68.5 % of students studied in other fields (primary school teaching, preschool education, pedagogy, arts, etc.). The students participating in research had just finished higher secondary school and on average achieved 19.6 points out of 34 (on average 57.6 % of all points, SD = 4.3) in final exams at the end of the secondary school. These data suggest that the pre-service teachers participating in the study show an average knowledge evaluated at the final exams (the knowledge is assessed in Mathematics, Slovene, foreign language, two elective subjects). The sample represented a predominantly rural population with mixed socioeconomic status.

Instrument

A 20-item paper-pencil questionnaire about liquid crystals (LCQ) was applied in October 2009. The LCQ was designed specifically for this study. The questionnaire consisted of three parts: (1) general information (age and gender, finished secondary school, score at the secondary school final exams, secondary school achievements in biology, chemistry and physics, and the field and the level of education of parents), (2) learning of science in the primary and secondary school (items about motivation for learning science), and (3) 9 items about liquid crystals (4 general items about soft matter, 4 items about general knowledge on liquid crystals, and 1 question related to a deeper understanding of phenomena related to liquid crystals). Sample items of the LCQ are presented in the Appendix 1.

The specific parts of the LCQ showed satisfactory measuring characteristics (i.e., the internal consistency reliability for the third part of the questionnaire - Cronbach's alpha was 0.62). The LCQ was administered to three university professors of chemistry, physics and chemical education. Their responses provided scientifically correct answers and content validation for the instrument. Students had 30 minutes to fill in the LCQ.

Data Collection

The research was a non-experimental, cross-sectional and descriptive study (Bryman, 2004). The students had received no special teaching about liquid crystals prior to testing. The LCQ was applied on the research sample within the groups of certain fields of study under normal examination conditions.

Descriptive statistics were used for illustrating the LCQ characteristics. The independent-sample t-test was used to explain the relation between the self-assessed knowledge and gender and student achievements on the LCQ. In addition, the one-way between-groups analysis of variance (ANOVA) was conducted to explore the differences in the LCQ scores regarding the study field of students. The $\chi 2$-test was used for illustrating the existence of statistically significant differences between the motivation of students for studying natural sciences and the knowledge about liquid crystals. 6 items about liquid crystals were analyzed in more detail. These questions were related to products, living organisms, the number of states of matter, the existence and properties of the liquid crystalline state and its structure.

RESULTS AND DISCUSSION

The analysis shows that, despite the fact that liquid crystals are so common, about two thirds of students (N = 448) have not yet heard of liquid crystals, and 72 % of them think that their knowledge about liquid crystals is negligible. This was confirmed by the LCQ results. Students on average achieved 1.5 points (SD = 1.4) out of 8 on the six questions that tested knowledge about liquid crystals. We expected that students would think logically and answer at least three out of the six questions. Specifically, we expected that those students who listed a product with liquid crystals, would know that there exist more than three states of matter and that the liquid crystalline state is one of the states of matter.

From the analysis of students' answers we get the following results: (1) 22 % of students listed a product with liquid crystals (the most common answer was LCD, other correct answers were LC thermometer, welding goggles, bulletin boards, jewelry), (2) 29 % of students recognized one property of liquid crystals (out of three), which is important for applications (22 % of students knew the importance of optical properties; 18 % of students were in error thinking that the density of liquid crystals is the crucial property), (3) 6 % of students answered that there are more than three states of matter, (4) 30 % of students knew or guessed that the liquid crystalline state is one of the states of matter, (5) 10 % of students correctly sketched the distribution of molecules in the liquid crystalline state, (6) 18 % of students thought that liquid crystals also occur in living organisms.

Therefore, the results obtained from analysis of the questionnaires show that student knowledge about liquid crystals is limited, which was partly expected since the topic is not included in the science curricula in schools.

25 % of students think that their knowledge about liquid crystals is good. 75 % of students have written that their knowledge about liquid crystals is negligible. It was expected that students who self-assessed their knowledge as good would achieve higher scores on LCQ. Students who self-assessed their knowledge as good, on average achieved 2.2 points out of 8 (SD = 1.4). Students who self-assessed their knowledge as negligible on average achieved 1.2 points out of 8 (SD = 1.2). The t-test was used for checking if there is a statistically significant difference in the LCQ scores between students who self-assessed their knowledge about liquid crystals as good and those who self-assessed it as negligible. The result of the t-test shows that the assumption of homogeneity of variance was justified (Levene F-test: $F = 1.228$, $p = 0.268$). The difference between the mean values is statistically significant ($t = 6.775$, $p = 0.000$). As expected, there is a statistically significant difference in the knowledge about liquid crystals for these two groups of students.

The research included 43 male students (10 %) and 405 female students (90 %). Male students on average achieved 2.6 points out of 8 on questions related to liquid crystals (SD = 1.9). Female students on average achieved 1.3 points (SD = 1.2). If the difference in knowledge regarding the gender was statistically significant, it was again checked by the t-test. The results show that the assumption of homogeneity of variance is not justified (Levene F-test: $F = 24.956$, $p = 0.000$). The difference in mean values in the number of points scored by gender is statistically significant ($t = 4.268$, $p = 0.000$). There are statistically significant differences in knowledge about liquid crystals regarding the gender: the male students showed better knowledge about liquid crystals than female students, which confirms the findings of Häussler and Hoffmann (2002) that male students are more interested in the technological application of science.

Since liquid crystals are a topic in chemistry and physics, it was expected that students in the field of natural sciences would have more knowledge about liquid crystals than students in other fields. Based on long-term experience, less successful students in secondary school decide to study the two subjects areas of teaching – chemistry and/or physics at the Faculty of Education. Therefore we expected that students in the other natural science studies would have a better knowledge than students of chemistry and/or physics and students in other fields. The study included 448 students. As already mentioned 15 % of students study chemistry and/or physics, 16.5 % students study other natural sciences (biology, home economics, computer sciences, mathematics or technology) and 68.5 % of students study other fields (primary school teaching, preschool education, pedagogy, arts, etc.). Students of chemistry and/or physics on average achieved 1.2 points out of 8 (SD = 1.3). Students of other natural sciences 1.9 (SD = 1.7) and students of other fields achieved on average 1.4 points out of 8 (SD = 1.2). Analysis of variance (ANOVA) was used to test if the difference in the average achievement is statistically significant. The Levene F-test shows that the assumption of homogeneity of variance is not justified ($F = 8.825$, $p = 0.000$). So Welch's approximation was used, which shows that the difference between the arithmetical means is statistically significant ($F = 4.729$, $p = 0.009$). Thus there are statistically significant differences in knowledge about liquid crystals between students of chemistry and/or physics and other natural sciences (the difference of arithmetic means is 0.66, $p = 0.011$). There are no statistically significant differences among the students of chemistry and/or physics and students of other fields (the difference of arithmetic means is 0.21, $p = 0.490$), but the statistically significant differences appear among students of other natural sciences and students in the other fields (difference of arithmetic means is 0.45, $p = 0.006$).

Information about the motivation of students to learn science subjects in primary and secondary schools has been acquired by the second part of the questionnaire. We were interested in the type of motivation for learning: how many students are intrinsically and how many are extrinsically motivated to learn biology, chemistry and physics? Students had to evaluate four statements. The first two were related to extrinsic motivation and the second two to intrinsic motivation. Students who highly agreed with the statements: “I learned, because I wanted to satisfy the expectation of the home environment," and "I learned because I did not want to be ashamed because of the lack of knowledge," are highly extrinsically motivated. Students who strongly disagreed with the statements "I learned because it was important for me to know the content and consequently get good grades," and "I learned because the subject was very interesting and I liked to learn it," are not intrinsically motivated. On average, 12 % of students agreed with the statements that they have learned the science subjects in order to satisfy the expectation of the home environment and did not want to be ashamed because of the lack of knowledge. This shows that 12 % of students are strongly extrinsically motivated to learn science subjects. On average, 34 % of students fully agreed with the statement that it was important for them to know the content and consequently get good grades, 37 % of students thought that the knowledge of biology is important, 34 % thought the same about chemistry and only 32 % considered that knowledge of physics is important. One of the statements in the questionnaire was connected to the intrinsic motivation, saying that they learned because the subject was very interesting and they liked studying it; 36 % of students said this for biology. The percentage of students, who claimed the same for the physics, is smaller: only 16 % of students found physics interesting to learn. Chemistry is for students less attractive than biology, but still more than physics, since 21 % of students agreed that chemistry is interesting to learn. We can conclude that for over one third of students biology is interesting and they are internally motivated to learn it, while the least popular is again physics. On average, 29 % of students are intrinsically motivated to learn natural science subjects, while the proportion of students who are intrinsically motivated to learn physics is the lowest.

Students who are either intrinsically or extrinsically motivated to study in general achieve better results on tests of knowledge. However, liquid crystals are a very specific topic, so we did not expect that motivated students would know more about liquid crystals than unmotivated students. The presumption was tested by the $\chi 2$-test. The results of the $\chi 2$-test show that there is no statistically significant difference between the intrinsically and extrinsically motivated students and students with low motivation for studying regarding the knowledge about liquid crystals ($\chi 2 = 186.2$, $p = 1.000$, $\chi 2 = 229.9$, $p = 0.948$). Therefore, our assumption, that in the case of knowledge about liquid crystals, motivation for learning science subjects plays no role was confirmed.

CONCLUSIONS AND IMPLICATIONS FOR TEACHING

A study on the informally obtained knowledge on liquid crystals prior to the university education, have been conducted. 448 pre-service teachers participated in the study by completing a 20-item paper-pencil questionnaire. All participants were in the first year university students and the study was carried out at the beginning of the school year. Since liquid crystals are not taught in the primary and secondary schools, it can be assumed that the knowledge tested was the knowledge obtained through informal education prior to the university level studies.

The final conclusion of the study is that, despite the fact that liquid crystals are common in everyday life, students have a very limited knowledge about them. Most of the students who had heard about liquid crystals related them to liquid crystal displays. There is a statistically different average number of points obtained in the questionnaire between the female and male students. Students who self-assessed their knowledge about liquid crystals as good also gained statistically significant better results than students who self-assessed their knowledge as negligible. There is also a statistically different achievement among the students in the different fields of study programs.

It was found out that the level of either the intrinsic or extrinsic motivation for learning science does not play an important role in the level of knowledge. This was expected, since we have tested the knowledge on a topic which was not taught in school.

The results of the study show that further work on this interdisciplinary topic, which should be included into physics and chemistry curricula, is worth the effort. Therefore we have designed a teaching unit on these novel materials, having in mind the following goals: (1) to design an interdisciplinary learning unit with several experiments (in science classes there is a lack of experiments even though students like experimenting), (2) to increase interest in science by connecting school science and students’ experiences (presenting science concepts integrated into authentic situations; applications of liquid crystals into the new technologies e.g. iPods, cell phones, laptops, etc. used by students).

In the literature a simple procedure for the synthesis of the MBBA liquid crystal can be found. Optimization of the synthesis makes it suitable for use in the chemistry classroom of the higher secondary schools (Verbit, 1972). Students can use the synthesized liquid crystal in the physics classroom to observe the optical properties of anisotropic materials (appearance of colours when a liquid crystal is put between two crossed polarizers, and a double refraction in a hand-made liquid crystal cell).

A pilot study was already set up. A procedure for synthesis of a liquid crystal was optimized, and simple basic experiments to observe and study some of the interesting properties of the liquid crystals were selected. The pilot teaching unit was prepared and tested with the first year pre-service teachers (Ziherl et al., 2010). The aims of the unit are: (1) to learn what liquid crystals are; (2) to introduce the students to an additional state of matter and (3) to show the special optical properties on which liquid crystal display (LCD) technology is built. We took into account the existing curricula for the higher secondary schools and tried to fulfil goals related to the states of matter, double refraction and synthesis of organic substances. From the curriculum analysis for secondary school we conclude that the topic could be included into the higher secondary school curricula, where at chemistry lessons students could discuss the states of matter, describe the structure of liquid crystals and synthesize MBBA in the school lab. At lessons of physics, liquid crystals could be included into optics (law of refraction, polarization of light) and they could be used as a model for other physical systems. At the same time students could see that the connection between different science fields is necessary for understanding liquid crystals.

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Appendix 1: Sample items from the liquid crystal questionnaire

Learning of science in the primary and secondary school

		I strongly disagree		I partly agree		I strongly agree
1. I learned, because I wanted to satisfy the expectations of the home environment.	at biology	1	2	3	4	5
	at physics	1	2	3	4	5
	at chemistry	1	2	3	4	5
2. I learned, because it was important for me to know the content and consequently get good grades.	at biology	1	2	3	4	5
	at physics	1	2	3	4	5
	at chemistry	1	2	3	4	5

Knowledge about liquid crystals

1. Have you ever heard of liquid crystals? ☐ yes ☐ no

2. If your answer to the 1st question is yes, where have you heard of liquid crystals?
   ☐ school ☐ book ☐ TV ☐ web ☐ journal ☐ other: ____________________

3. How much do you know about liquid crystals? ☐ something ☐ nothing

4. Do you know in which products liquid crystals are used? Please write down as many products with liquid crystals as you can remember. ____
   ____

5. From the list below choose the properties of liquid crystals which are crucial for their use in the technological applications.
   ☐ optical properties – birefringence
   ☐ optical properties – colours
   ☐ electrical properties
   ☐ magnetic properties
   ☐ fluidity
   ☐ viscosity
   ☐ density
   ☐ other: ____________________________