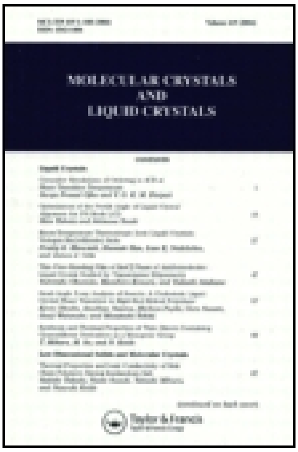

Molecular Crystals and Liquid Crystals

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Development of Some Natural Science Competences in Undergraduate Study by Training Visualization Skills on Subject Liquid Crystal Phases and Structures

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Development of Some Natural Science Competences in Undergraduate Study by Training Visualization Skills on Subject Liquid Crystal Phases and Structures

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Understanding physical phenomena often requires a comprehensive imagination of the subject. Visualization software uses two main approaches for presenting three-dimensional (3D) physical systems in two dimensions (2D): 3D virtual simulation (3D view) or 2D cross-sections (2D view). We focused on liquid crystals (LCs) in our comparative study of comprehension of both views for two groups of students: unfamiliar and familiar with LCs. We found that students with experiences in this field prefer the use of 2D view while other students are significantly worse in interpretation of 2D views.

Keywords 3D Visualization; liquid crystals; natural science competences; physics education

1. Introduction

There are many topics in physics, e.g., rotation of rigid bodies, hydrodynamics, electrostatics, magnetism, etc., as well as the topics in chemistry and biology, where a good three-dimensional (3D) spatial imagination of the system is needed in order to understand the problem properly. Since the 3D systems have to be projected into two dimensions (2D), e.g., on paper, panel or computer screen, the students should be able to interpret such images/representations concisely. This ability can thus be treated as an important natural science competence. However, it is not always easy to make a clear visualization of 3D pictures in 2D presentations [1].

With respect to visualization software, there are two main options for presenting 3D physical systems in 2D: either by simulating 3D pictures (for instance with VRML files; VRML = Virtual Reality Modelling Language) or by 2D cross sections

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of the system [1–5]. These two possibilities are henceforth referred as 2D and 3D view, respectively. Our experience in other fields indicates that it is more appropriate to use 3D view as a starting point when the students are essentially unfamiliar with the topic, since the 2D view is not comprehensible enough for them. VRML files offer the user some standard operations: rotation, zooming, shift, etc., but their creation demands a lot of programmer's time and effort. On the contrary, students familiar with the subject prefer using 2D view since it provides more information about the physical system in significantly shorter time.

In our investigation of the concepts and performance of 2D and 3D views, we choose the field of liquid crystals (LC) for several reasons. LC exhibit a rich variety of phases, structures and 3D patterns, including director field deformations, point and line defects [6,7] and domain patterns [8] and are therefore perfect for studying various geometric views and aspects. LC structures and corresponding mathematical models have many analogies in nature: theory of the development of defect structures in the universe, supra-fluidity, superconductors, ferromagnetics and ferroelectrics, etc. [9–13]. In this respect, the study of LC offers a nice example of science inter-connectivity: they are often used as testing grounds of universal physical phenomena. Their main advantages with respect to other systems are softness (i.e., susceptibility to relatively weak perturbations), liquid character, optical anisotropy and rich variety of LC phases & structures. Next, while this subject is considered very poorly in regular education, even in high school, some of our students worked on LC extensively (graduation, seminar works and similar), and this makes a significant differences in our students' knowledge of LC, which is suitable for our research.

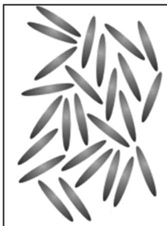
In our investigation the use of the web and some VRML files (created by one of the authors) is demanded and this is related to the digital competence as one of the eight key competences from the EU Legislation – Education, Training, Youth (Key competences for Lifelong Learning) [14]. In October 2008 the Slovene national project Development of Natural Science Competences began and it will finish at the end of 2011 [15]. Its goal is to indicate better didactics strategies for systematic development of students' natural science competences in the frame of regular education. This study was partially done in the frame of the project. Our VRML files were originally created for the use in another investigation about successfulness of introducing contemporary scientific and technological achievements in physics in primary school.

2. Test for Students of Physics

All students in the test were trained in using 3D software before testing. The selected LC themes were LC phases (nematic, smectic A and C) and structures [16,3]. The configurations were either defect-less, or they included point and line defects [17], or displayed domain-type textures. Students unfamiliar with LCs were compared to students which have already met this topic (seminar works and similar).

So far, only the physics students and university graduates from the Faculty for natural sciences and mathematics at the University of Maribor have cooperated. The test (questionnaire) contains 19 questions with 4 possible answers for each. In most cases only one answer is correct, but for some questions two answers have to be selected (students were not told how many answers are right). For each task a student gained 0 (completely wrong answer/answers), 1 (partially correct answer/answers) or 2 (correct answer/answers).

1. task
What can you tell about the spatial distribution of the molecule mass-centres and their orientations in the LC phase shown in this 2D presentation of real 3D sample?

	☐ mass-centres of molecules are randomly distributed in space, while their orientations are randomly distributed in the 2D plane ☐ mass-centres of molecules are randomly distributed in space, and so are their orientations ☐ mass-centres of molecules are not randomly distributed in space, but their orientations are randomly distributed in the 2D plane ☐ mass-centres of molecules are not randomly distributed in space, but their orientations are

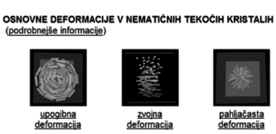
(a)

5. task
What can you tell about the spatial distribution of the molecule mass-centres and their orientations in the phase presented on this VRML file?

Use the web page: http://www.repnik.com/complex/tk_vrml/index.htm and run the 3D file by clicking on the text "**smektična A faza**" (A smectic phase) 	☐ mass-centres of molecules are randomly distributed in space, and from their directions in space some definite average direction can be noticed ☐ mass-centres of molecules are randomly distributed within individual layers, and their average direction is perpendicular to the layers ☐ mass-centres of molecules are randomly distributed in space, and their average direction is perpendicular to the layers ☐ mass-centres of molecules are randomly distributed within individual layers, and their average direction is parallel to the layers

(b)

8. task
Average local orientation of molecules is described by the unit vector ***n***. The 3D file below shows the twist structure with cylindrical symmetry. This structure is described here by Cartesian or cylindrical coordinate system with directional vectors $\boldsymbol{e}_r$, $\boldsymbol{e}_\varphi$ and $\boldsymbol{e}_z$ in radial, azimuthal and cylinder-axis directions, respectively. Which of the equations on the right is (are) correct?

Use the web page: http://www.repnik.com/complex/tk_vrml/index.htm and run the 3D file by clicking on the text "zvojna deformacija" (twist deformation) 	☐ $\boldsymbol{n} = \boldsymbol{e}_r$ ☐ $\boldsymbol{n} = \boldsymbol{e}_\varphi$ ☐ $\boldsymbol{n} = \boldsymbol{e}_z$ ☐ $\boldsymbol{n} = (\cos kz, \sin kz, 0)$

(c)

Figure 1. The structure of different tasks about 2D and 3D visualization a) 2D nematic phase, b) smectis A phase, c) twist deformation.

The physical contents of the tasks are the following. The first few questions are addressed to characteristic phases: isotropic, nematic and smectic A [18]. The following questions are given in regard to different deformations of the nematic director field: splay, bend, twist and double twist. The third set of tasks touches the point and line defects in LC [7,17,19]. The last three questions are about LC domains. There are different structures of the tasks: deduction from 2D cross-sections to a 3D picture or vice versa, relation between the mathematical model of the nematic director field and the 3D structure, understanding the statements describing the structures, and last, in our opinion the most difficult task – deducing possible 2D view from 2D views in different cross-sections. To solve the last task, the composite $2D \rightarrow 3D \rightarrow 2D$ transformation must be done in one's imagination. A few questions with answers in the test are shown in Figure 1.

3. Results of the Test and Discussion

There were 7 persons (post-graduate students and co-workers in our institutions) with some knowledge in LC (Group I) and 8 students without any experience in this field (Group II) who cooperated in this investigation, all persons briefly called students. Table 1 shows the results for both groups. Tasks are grouped into categories (labeled from C1 to C7) and all points for the whole group of students and for all tasks in each category are summed in the table.

Meaning of the categories of tasks in Table 1:

- C1: textual interpretation of 2D figures
- C2: textual interpretation of dynamic 3D (VRML) views
- C3: textual interpretation of static 3D figures
- C4: translation of static 3D view into a pair of 2D cross-sections
- C5: translation of 2D cross-section into another 2D cross-section
- C6: translation of dynamic 3D view into 2D cross-section
- C7: translation of a pair of 2D cross-sections into dynamic 3D view

Table 1. Number and percentage of achieved points by categories for both students' groups. For instance, the denotation 30/42 points at the top of the first column means 30 points of 42 possible ($42 = 3 \times 2 \times 7$; 3 tasks in the C1 category –1, 9 and 10, 2 maximum points for each task, 7 students)

	Group I		Group II		Both groups	
Categories of tasks	Points	Percent	Points	Percent	Points	Percent
Cl: 1, 9, 10	30/42	71.4	19/48	39.6	49/90	54.4
C2: 2, 3, 5, 6, 7, 8, 19	54/98	55.1	42/112	37,5	96/210	45.7
C3: 4, 11, 17, 18	36/56	64.3	36/64	56.3	72/120	60.0
C4: 12	7/14	50.0	12/16	75.0	19/30	63.3
C5: 13, 14	17/28	60.7	15/32	46.9	32/60	53.3
C6: 15	9/14	64.3	11/16	68.8	20/30	66.7
C7: 16	11/14	78.6	12/16	75.0	23/30	76.7
All tasks	164/266	61.7	148/304	48.7	312/570	54.7

The tasks in the first three categories where different figures have to be interpreted were solved by Group I significantly better than by Group II. Furthermore, the comparison between C1 and C2 indicates that for Group I the 2D figures are more informative than 3D views while for Group II the results of C1 and C2 are similar. The main conclusion of this investigation is, however, the comparison of results for both groups of students when the tasks start from the 2D view (categories C1, C5 and C7) or 3D view (categories C2, C3, C4 and C6), respectively, regardless of the goal of the answer (either 2D or 3D view or textual interpretation). In the expert group the results are generally better when the 2D view is the starting point as compared to the 3D view. On the contrary, the 3D view is preferable as the starting point for non-experts.

It may happen that the non-experts solve some tasks even more successfully than the expert group. This was the case for the task 12 with the so called radially twisted or double twisted structure where the nematic director twists about any radial axis perpendicular to a symmetry breaking cylindrical axis. This structure is usually unfamiliar even to LC experts because it appears in rare circumstances: in chiral nematics in confined cylindrical symmetry with appropriate boundary conditions [20,21] and it probably also constitutes the "blue phases" of LC [22]. Maybe experts are burdened with the LC knowledge and try to remind themselves of other commonly known structures of LC so that they choose the wrong answer while the non-experts just try to visualize and imagine the drawn structure.

Finally, it should be noted that our developed VRML files and other visualization tools for presenting LC were also used in another investigation where the successfulness of introducing some contemporary scientific and technological achievements in the field of physics in primary school was tested [23]. Practical use of LC was one of the 12 tested topics; the others are nuclear power, optical cables, photovoltaic cells, Universe and planets out of our solar system, etc. Three approaches in school practice were compared: 1) pure frontal lessons, 2) individual pupils' work with printed learning materials and 3) frontal lessons implemented with the use of Information Communication Technology (ICT). This investigation showed that for some contemporary physics topics the combination of frontal work with ICT is favorable (where the use of visualization tools described in this paper is included).

4. Conclusion

The 2D representation (using different cross-sections) of a physical 3D system is preferable for experts in the field since the proper 2D visualization gives more concise information than the 3D view. On the contrary, the 3D active representation (in particular using VRML files) of the system is more appropriate for the beginners. Another investigation showed that the combination of frontal work with Information Communication Technology (where the use of VRML files and other visualization tools described in this paper is included) is successful for introduction some contemporary physics topics, such as the use of LC, in primary school.

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