-Abstract-

One of the central practices of biochemists is using various software, such as Jmol, for molecular modeling of proteins. Through Jmol, high-school biotechnology majors (11^{th} and 12^{th} grades) in Israel are visualizing molecular models of proteins through the mediation of computerized tasks, as one of the requirements of the biotechnology curriculum towards the matriculation examination. A conceptual framework that defines molecular modeling of proteins by high-school students was developed as part of this study and served as a theoretical and methodological tool for analyzing the findings obtained in the study. Two theoretical frameworks were incorporated into this conceptual framework: one dealing with specific components of scientific knowledge and the other with cognitive skills related to visual representations commonly used by expert biochemists. This conceptual framework includes four components of knowledge that were characterized in this study as those used by students who study through computerized Jmol tasks, which were designed in the course of this study: C, P1, P2 and E: i) The content knowledge component, C, includes knowledge about protein structure and function; ii) The procedural knowledge component, P1, includes knowledge about the use of visual representations in the molecular model; iii) The procedural knowledge component, P2, includes knowledge about using the Jmol software options for molecular modeling of proteins; iv) The epistemic knowledge component, E, includes knowledge about the molecular model as a scientific tool. This conceptual framework was used to analyze the data obtained in the course of this study.

The first purpose of this study is to characterize Jmol tasks from the learning environment "Bioinformatics in the service of biotechnology". First, an analysis of the contents of two Jmol tasks, IPNS and AFP, which were retrieved from the learning environment, was conducted. A hierarchy was found in the use of the knowledge components. In each segment of information or a question in which procedural knowledge, P1, was identified, content knowledge C was also found. In addition, in each segment of information or a question in which procedural knowledge P2 or epistemic knowledge E were identified, content knowledge C and procedural knowledge P1 were also detected. Thus, the various knowledge components are tightly connected to content knowledge and cannot be separated from it. It was also found that there are significant differences in the frequency of representation of the procedural knowledge components P1 and P2 in the information segments, compared with the frequency of their representation in the questions that appear in both tasks. While in the information segments, procedural knowledge P2 is dominant, more questions are specifically directed at procedural knowledge P1.

The second purpose of the study is to examine the students' learning performances and characterize the learning processes of students while learning through the Jmol tasks that are included in the learning environment. The findings were obtained by combining quantitative and qualitative methods. In the quantitative part, knowledge questionnaires were used (n=70 biotechnology majors). In order to characterize scientific knowledge acquisition by the students more deeply data were collected from observations and interviews and analyzed qualitatively. In this part of the study, four female students participated in two pairs and served as case studies. The quantitative findings indicate that the use of tasks and Jmol significantly improved the high-school students understanding of proteins, i.e. students acquire content knowledge C and procedural knowledge P1 while using the Jmol software and the accompanied tasks. However, in view of the students' performance, the improvement in knowledge is

still only relative, and it cannot be concluded that their level of knowledge about proteins is high. In addition, there was a difference between a group of students who began learning with a relatively limited knowledge about proteins (group A) and the second group of students who began learning with a greater knowledge about proteins as a result of their participation in a research project on the protein PON1 (group B). Group A showed a significant improvement in learning through Jmol compared to the improvement found in group B. While group B performance improved significantly in two of the five sub-components of knowledge following Jmol learning, group A performance improved significantly in all sub-components: decoding and constructing visual representations, as well as content knowledge about structure, function, and the relationships between protein structure and function.

The qualitative findings were analyzed according to axis describing expertise in disciplinary subject matter and includes three stages: acclimation, competency, proficiency and the intermediate stages between them. The findings indicated that the students in both pairs were in the acclimation stage during learning through the Jmol tasks. For the most part, the pair of students who participated in the research project, which focused on the structure and function of the PON1 protein, showed an extensive knowledge of the procedural knowledge component P1 and presented a more efficient use of the procedural knowledge P2. However, the analysis has revealed two situations that present a challenge in acquiring knowledge among students from both pairs: i) the acquisition of scientific knowledge that includes only some of the components of knowledge required to give a complete answer to a question; ii) the use of incorrect scientific knowledge in one of the components of scientific knowledge in response to a question. It follows from this that although learning through Jmol tasks can provide an opportunity to acquire authentic scientific knowledge about proteins, the discourse reveals complexity in students' learning processes, and the acquisition and development of students' conceptual-scientific knowledge about proteins does not necessarily occur fully during task response.

The third goal of this study is to examine the perceptions of students and teachers about learning through the use of Jmol tasks. Towards this end, questionnaires were collected and analyzed from 163 students and interviews were conducted with two teachers. It was found that students see the procedural knowledge P2 as a major source of interest in learning, although their experience in using the software options is felt as a complex cognitive skill. In addition, students perceive the procedural knowledge P1 as a source of knowledge about proteins, especially in relation to protein structure. The teachers' perception was not significantly different from that of the students.

An examination of the learning processes and perceptions shows that the use of students in Jmol tasks, developed according to the assumption that molecular modeling of proteins by high-school students is a primary goal of learning, does not necessarily promote the acquisition and development of students' conceptual knowledge about proteins. The conceptual framework for molecular modeling of proteins by high-school students, developed in this study, was designed with the aim to analyze data obtained in the study. However, researchers, materials developers, and teachers interested in developing, designing, and using learning materials that combine molecular modeling software may find it interesting and useful. Future use of the conceptual framework may reduce the challenge of acquiring scientific knowledge about protein structure and function among students, and may help bridge the gap between authentic scientific practices involved in protein research and the acquisition of scientific knowledge about proteins in high-school.