

# Research on conceptual understanding of thermodynamic and transport phenomena of solids - microscopic models of electrical and thermal conductivity

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**Abstract.** Knowledge of solid-state physics, such as electrical and thermal conductivity, is very important due to its influence on the development of modern technologies. Although these phenomena appear in the curricula of elementary school, secondary school and universities, students have many incorrect ideas about them. In order to gain detailed insight into students' understanding, we have developed a concept inventory on microscopic models of electrical and thermal conductivity of solids (METCS). By applying the test to a sample of Croatian first-year university students, some already known incorrect ideas were confirmed and a large number of new ones were discovered.

## Introduction

The development of modern technologies depends, among other things, on knowledge of solid-state physics [1]. Therefore, the understanding of phenomena such as thermodynamic and transport phenomena of solids, with emphasis on their electrical and thermal conductivity, is developed at all levels of education through the application of various physical models. At the same time, there are difficulties in understanding, as shown by the results of a relatively small number of educational researches, especially when it comes to microscopic models of the mentioned phenomena [2–9].

To make teaching more effective, it is advisable to identify, analyze and correct students' incorrect ideas in order to create high-quality physical models. Conceptual tests [10] are used to identify mentioned incorrect ideas.

Further to the above, we developed the multiple-choice concept inventory to test students' understanding of microscopic models of electrical and thermal conductivity of solids (METCS). The concepts related to the METCS included in the curricula of Croatian universities, high schools and elementary schools were considered. They were categorised into the five conceptual groups related to solids: (i) microscopic structure, (ii) motion of particles at a certain temperature, (iii) motion of free charge carriers under the influence of an external electric field, (iv) electrical conductivity in temperature dependence, (v) thermal conductivity [11].

## Methods and findings

Based on the literature review and the results of our initial research [2], we developed the METCS concept inventory, which has been shown to have good psychometric properties. The inventory contains 27 multiple-choice questions. The quantitative study, which was conducted as part of the development of the METCS inventory, was carried out in the academic year 2022/2023 on a sample of 233 undergraduate students from the University of Rijeka (Croatia) using the paper-and-pencil method. Our target sample were students of the first year of university studies, where the courses on the relevant concepts were taught.

By analyzing the results obtained using the METCS test, some already known incorrect ideas were confirmed, but numerous new ones were uncovered. For example, our students mistakenly

believe that free electrons in a metal move exclusively in a straight line under the influence of an external electric field or that the electrical conductivity of a metal increases with increasing temperature, which is consistent with the results of previous studies [2,3,7]. Newly discovered incorrect ideas include, for example, statements that (i) free electrons in metals mainly collide with ions that are in an equilibrium position within the crystal lattice, or with each other like gas molecules; or that (ii) heat is mainly conducted by the vibrations of the lattice ions in a conductor and by the collisions of the free electrons in the insulator.

## Conclusion

Concepts related to the METCS are included in curricula at all levels of education, as they form the basis for training qualified professionals in the relevant STEM fields. However, due to their abstract nature, these concepts are often incomprehensible to students. With the aim of gaining a comprehensive insight into the understanding of METCS, we have developed the METCS concept inventory. The results of our research can help in developing appropriate teaching methods in accordance with the guidelines of modern teaching strategies [12], using modern teaching tools [13].

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