Intensive and extensive properties as a crosscutting idea: the case of teaching density

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Abstract. Cross cutting concepts have been introduced formally as a set of items and are meant to bridge disciplinary borders. They can potentially provide students with an organizational framework for connecting knowledge from the various disciplines. Trying to support this direction, we introduce the Intensive and Extensive Properties as an idea that cuts across science disciplines. This study focuses on 7th grade students' preconceptions about density as an intensive concept. 241 students participated into the study. The results showed that 22% realize that density is an intensive quantity and does not depend on the amount of the system.

Introduction

Crosscutting concepts, or CCCs, are overarching ideas that connect different fields of science and engineering. CCCs were introduced in 2012 and are meant to bridge disciplinary boundaries, providing students with an organizational framework for connecting knowledge from various disciplines into a coherent and scientifically based view of the world [1]. The seven CCCs are patterns, cause and effect, scale and proportion, quantities, systems and system models, energy and matter, structure and function, stability, and change. Some researchers have proposed other crosscutting ideas that could help students develop a deeper understanding of science and engineering [2]. Trying to support this direction, we introduce the Intensive and Extensive Properties (IEP), which refers to physical quantities that are either independent of the amount of the system (intensive) or dependent on the amount of the system (extensive) [3]. Examples of intensive concepts include density, pressure, temperature, concentration, mole fraction, and molality, while extensive concepts include mass, volume, energy, entropy, and enthalpy. The case of density may suggest that effective instructions should take into account the IEPs to support learners with scientific understanding of other intensive concepts. The students' prior knowledge regarding the concept of density from IEP viewpoint has been revealed in preliminary research, which we also analysed and discussed.

Theoretical framework and research questions

Density is a concept widely regarded as difficult for secondary school students to comprehend [4]. Despite being a fundamental concept in physics, chemistry, and engineering, alternative conceptions of density are prevalent among both students and pre-service teacher candidates [5]. Although mass and volume are also crucial extensive concepts, density is an intensive property that must be considered alongside these other concepts. Multiple studies have attempted to enhance students' understanding of density through various interventions [6], but few have explored density's relationship with volume and mass from the IEP perspective. This study aims to investigate students' preconceived notions of density from the IEP viewpoint, with the following research question of interest: **What is the frequency distribution of alternative and scientific perceptions regarding density as an intensive property among students?**

Methods and Findings

The research paradigm described in our work is quantitative-correlative research. The study was conducted during the academic year 2021/2022. A total of 241 seventh-grade students from

six schools located in northern Israel participated in the study. Of these students, 113 were female, while 128 were male. The data was collected using a research-based test that was translated into Arabic and validated by a facilitator and a colleague in the field of physics teaching. The test consisted of six multiple-choice items concerned directly with the IEP; each also requires a justification for the answer. Table 1 presents the results of our study on the perspectives of intensive and extensive students. According to the data, the average percentage of answers indicating intensive (scientific) views was 22%. In contrast, the average percentage of answers indicating extensive (non-scientific) views was 39.5%. The remaining students have varying misconceptions about density depending on the context or on the vessel.

Table1. Percentages of students' responses regarding the perspectives of intensive and extensive.

view	Q1 (%)	Q2 (%)	Q3 (%)	Q4 (%)	Q5 (%)	Q6 (%)
Intensive	34	18	34	11	19	17
Extensive	22	52	31	59	32	41
Vessel dimension	19	7	13	1	25	9
Miscellaneous	25	23	22	29	24	33

Conclusions and future research

The study revealed that many students held differing opinions regarding the fundamental nature of density as an intensive property. Our results pertaining to density may serve as a foundation for advancements in three distinct research areas. Initially, subsequent mixed-method studies ought to concentrate on instructing density using the IEP. Secondly, undertaking research from the IEP perspective should concentrate on additional scientific concepts, including pressure, concentration, or temperature, which are deemed intensive and central to CCCs. Lastly, the incorporation and integration of IEP into science and engineering textbooks, as suggested in [7], may prove to be advantageous.

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