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Exploring Students' use of Basic Scientific Concepts in Higher Education

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***Abstract*—The purpose of this study was to explore engineering students' ways of solving problems specific for material technology and thermodynamics. A written questionnaire was used for data collection. Results show that establishing an understanding for fundamental scientific concepts is a process that takes time. The concepts in focus have been part of the school curricula since the compulsory school level, and for many of the students the concepts were still not established. The amount of time required to acquire concepts becomes especially important for discussions concerning a broadened student recruitment, where a change in prerequisites for university level education may lead to students who have less understanding for fundamental concepts, and thereby contribute to a reduction in the quality of higher education.**

***Index Terms*—engineering students, concept development, conservation of mass, particulate nature of matter**

I. INTRODUCTION

This study was designed to explore the ways in which students solve problems related to material technology and thermodynamics. The concepts in focus were the concepts that form the basis for understanding the particulate nature of matter and conservation of mass. These concepts are of special importance for engineers as they also form the basis for environmental analysis and natural spread patterns. Unfortunately, many of these concepts are theoretical, abstract, and not accessible for direct experience. Studies focusing on university students' perspective and use of the concepts involved in understanding the particulate nature of matter are limited. This study was designed to fill this gap in the scientific literature.

II. BACKGROUND

A. Cultural historical theory

This project takes its stance in cultural historical theory, where the historical aspect of our cultures and current knowledge is recognised. Learning is here seen as social, but not something that is achieved in a general and universal manner. We notice different things in our environment and interpret these things in different ways and in different situations. This individual prism [1] is an important perspective of learning, since it suggests that almost all students will have their own interpretations of some aspects of a formally introduced content. Exploring students' own interpretations of science content is something that educational research has been pursuing for decades. The interpretations that do not coincide with the scientific content have been classified in many ways, and 'misconceptions' or 'alternative conceptions' are two of the more common terms [2]–[6].

The particulate nature of matter, energy and matter, natural cycles and conservation of mass are areas that have been defined as core ideas within science and engineering education [7], [8]. These core ideas were derived especially to support engineering students' learning and for bridging the gap between science and engineering.

Understanding the nature of matter is fundamental for learning science [3], [9] as it provides the means to make theoretical assumptions about particle movement and transport in natural systems as well as about the macro-level properties of matter [10]–[13]. However, understanding the particulate nature of matter is by no means an easy task [9], [10], [14]–[23] as it includes personal interpretations of a series of interrelated concepts and requires a theoretical sub-microscopic perspective of the world.

B. Previous research on students' conceptions of the particulate nature of matter

Research shows that developing an understanding of the particulate nature of matter is a process that takes considerable time [14], [15], [17], [20], [20], [24]–[27] as there are many concepts involved and the concepts are connected in specific ways to conceptual frameworks. The learner then also needs to use the concepts often enough for them to become a natural part of their problem-solving strategies [9], [15]–[18], [20], [22].

When turning to research exploring students' conceptions of the different concepts involved, it has been shown that especially mass and energy are difficult areas for students. It is not uncommon for learners to believe that mass can be transformed into some form of energy through physical and chemical change [26], [27] or that matter is lost during phase transitions [14], [25]. The causes of some of these difficulties have been suggested to be either alternative interpretations of Einstein's famous formula: $E=mc^2$ [28], or more informal conclusions drawn from visual experience where matter seems to disappear when transformed into something that is not directly visible [15], [17]. Indeed, visual experience is a key factor for students' learning, as it also has been shown that it is not uncommon to view mass as increasing when items appear to become more compact, for example, when a substance changes from gaseous to liquid state [29], [30]. Another possible reason for why students believe in loss of mass during phase transitions, aside from visual experience, may be their failure to separate the mathematical formula for calculating density from the meaning of the concept density, as describing compactness. The mathematical formula ($\rho = m/V$) could be interpreted as a formula where mass is related to volume [26], [31]. Failure to distinguish between concepts and algorithmic problem-solving is not uncommon for learners [26], [32], [33]. This may in fact be unintentionally supported by both teachers and learners, as teaching over different educational levels tends to become more focused on algorithmic problem-solving and less focused on conceptual understanding [34]. Research results also suggest that older learners become more focused on finding the correct answer than understanding the problem at hand [16], [35]. Conclusions drawn from this research point to the importance of revisiting and using concepts on a regular basis and thereby enhancing them [24], [25].

Naturally, this multitude of theoretical concepts, mathematical procedures and their interrelatedness increase the chances of developing a manifold of individual interpretations of concepts, that in turn lead to individual explanations [36].

Aim of study

The aim of this study is to explore engineering students' own interpretations and use of fundamental concepts for understanding the particulate nature of matter. The research questions can be formulated in the following manner:

1. What concepts do students use when solving problems concerning the particulate nature of matter?
2. To what extent and frequency can alternative conceptions regarding preservation of mass during phase and chemical changes be found within this student group?
3. How do the concepts used affect the accompanying problem-solving tasks?

TABLE I
SUMMARY OF STUDENTS PARTAKING IN DATA COLLECTION

Degree and programme[a]	Year in programme	Nr of students
M.Sc. in *Me*, B.Sc. in *Me*	2	55
M.Sc. in *Me*, B.Sc. in *Me*	3	27
M.Sc. in *Ie*	3	42
M.Sc. in *Cs*	3	13
M.Sc. in *Et*	3	9
M.Sc. (failed to specify)	3	4

[a] Mechanical engineering *(Me),* industrial economy *(Ie),* computer electro-technology *(Et)* and computer security *(Cs).*

III. METHOD

A. The context of the study

This study includes 150 students attending engineering programmes as the five-year master's degree (M.Sc.) and the three-year bachelor's degree (B.Sc.). The specific programmes are (mechanical engineering *(Me)*, industrial economy *(Ie)*, computer electro-technology *(Et)*, and computer security *(Cs)*. For a summary see Table 1.

TABLE 2
SUMMARY OF UNIVERSITY CREDITS FOR THE MAIN SUBJECT IN DIFFERENT PROGRAMMES

Programme	Credits within their main subject
M.Sc.	150 (2.5 years of full-time study)
B.Sc.	90 (1.5 years of full-time study)

[a] The timespan of courses is measured by using a point system, where 1.5 university credits are equal to one week of study.

A summary of the university credits for the main subject in different programmes are provided in Table 2. The number of courses with physics content is higher for the students attending the mechanical engineering and electro-technology programmes than for the students attending industrial economy and computer security.

The prerequisites from upper secondary education for entrance into these programmes were basic mathematics, physics and chemistry, except for students entering a B.Sc. in mechanical engineering and a M.Sc. in computer science where basic chemistry courses were not a prerequisite. Despite this, most students entering these programmes had basic chemistry knowledge as the majority had attended the science or technology programme at the upper secondary level. At the time of data collection, the students had started the second or third year of their degree programme.

All students included in the study have completed courses in mechanics, environmental strategy and sustainable development. The mechanics course addresses concepts such as mass, energy and density. In the environmental strategy and sustainable development course, some of the concepts included are pH, concentration and energy. Most of these students also completed a course in electricity, which again includes concepts of energy. The mechanical engineering students had also completed courses in dynamics, wave physics, material science and mechanics of materials, all of which include concepts such as mass, energy and density.

This study also included a control group composed of 66 pupils studying the science and technology programme in upper secondary school (17 years of age). Comparing results from these two groups provides a developmental perspective on the use of concepts. All the pupils included in the control group had studied one course in chemistry and had also attended a few weeks in one course in physics that included density and motion.

Ethical consent was obtained from the students/pupils themselves in accordance with GDPR (General Data Protection Regulation).

B. Data collection

Data were collected using a research instrument identical to that of Andersson et al. 2003 [37] which was originally developed by Andersson [38]–[40] for the purpose of exploring secondary school students' understanding of matter (see appendix).

The research instrument was composed of a series of multiple-choice questions together with requests for additional written explanations.

C. Data analysis

Data analysis, i.e. categorisations, was performed by both authors independently, and categories were then compared and discussed. Data were summarised so that the individuals' explanations were easily visualised. For the second categorisation, explanations were merged using each multiple choice as a heading with the subcategories of *less weight*, *no weight* and *weighs more than before*. In the third categorisation, explanations were coded, and then the codes were merged while maintaining the answers and subcategories as headings. Not all students/pupils answered all of the questions; also, the students/pupils who provided a correct explanation were categorised as correct even if they provided the wrong multiple-choice answer. Students who provided a correct-choice answer, but an incorrect explanation, were categorised as incorrect, and their explanations were then further analysed.

IV. RESULTS

There was no significant difference in the data derived from the different groups of engineering students despite the fact that they had attended a different number of kinds of physics courses; therefore, the data from the five groups were merged in the following quantitative and qualitative analysis. There was no significant difference in answers between the different upper secondary programmes; therefore, also these groups were merged.

TABLE 3
PERCENTAGE OF ANSWERS PER QUESTIONS FOR PHASE CHANGE

Weight change	Ice melting.[2] (%)	Freon evaporates.[2] (%)	Sugar dissolves in water.[1] (%)	Combustion, gas formation.[2] (%)	Carbonated soda decarbonates.[1] (%)
Increase	15/18	5/2	1/0	11/14	5/8
No change	**71/61**	**53/50**	**63/59**	**57/53**	25/29
Decrease	14/21	37/48	34/41	28/30	**66/62**
Don't know	0/0	2/0	1/0	2/3	2/0
Wrong explanation[3]	0/0	3/0	1/0	2/0	3/2

Percentage of engineering students/upper secondary school pupils, respectively (150/66 total respondents). Correct answers are indicated in bold text. [1]Open system, [2]closed system, [3]students who provided a correct-choice answer, but an incorrect explanation were categorised as incorrect.

Frequency of alternative understandings, a comparison between engineering students and upper secondary school students

When data were organised according to questions and correct answers, a large percentage of the students, in one case as much as 47%, suggested weight change in a closed system during physical change (Table 3). In an open system where gas evaporates, 25% suggested that the weight would be unchanged and 5% that the weight would increase. The question with the greatest number of correct answers (71%) concerned the weight of melting ice in a closed system. When comparing engineering students to upper secondary pupils, the number of correct answers for the same question (ice melting in a closed system) was only 4-10 percent higher for the students than the upper secondary pupils' answers.

TABLE 4
ANSWERS WHETHER OR NOT AIR AND HEAT HAVE WEIGHT

	Air has weight (%)	Heat has weight (%)
Yes	**71/76**	13/15
No	29/24	**85/85**

Percentage of correct answers of engineering students/upper secondary school pupils, respectively, in percentage on problems based on what has weight (150/66 total respondents). Correct answers are indicated in bold text.

On a question regarding weight change for gas evaporating from an open system, 25% of the students answered that the weight remains the same. These answers can be partially explained by the fact that 29% of the students did not believe that air has weight (Table 4).

When comparing the engineering students' answers to the answers from the group of pupils, 76% of the pupils answered that air has weight, while 71% of the students answered that air has weight. The miniscule difference suggests that these concepts had not developed much since upper secondary school.

Nonetheless, 25% of the engineering students provided correct answers to all the presented questions, compared to 18% of the reference group.

Students' explanations

Not all of the students provided written explanations when requested to do so, but most of the students who provided correct answers did also provide a scientifically accepted explanation for their answers. The explanations deemed incorrect were mainly because students used explanations based on macro-level assumptions. The majority of answers that were deemed incorrect were followed by explanations that can be seen as based in alternative understandings. The following main categories were found: 1) *Confusing mass and density*, 2) *Believe mass can turn into heat or pressure or vice versa*, 3) *Mass appears, disappears or substances have no weight*. For a distribution of the alternative explanations within the categories, see Table 5. The remaining answers did not fall into any of these categories.

Although all of the learners included in this study have extensive cultural and practical experience concerning the result of melting ice, this was the question where the majority of students'/pupils' answers (44/52%) included a mix-up of the extensive property mass and the intensive property of density.

TABLE 5
PERCENTAGE OF ANSWERS OF ALTERNATIVE EXPLANATIONS

Category	Ice melting.[2] (%) (43/25)[3]	Freon evaporates.[2] (%) (70/31)[3]	Sugar dissolves in water.[1] (%) (55/26)[3]	Combustion, gas formation.[2] (%) (65/33)[3]	Carbonated soda decarbonates.[1] (%) (51/24)[3]
1)	**44/52**	19/6	11/0	12/0	10/8
2)	2/4	11/0	0/0	8/6	6/17
3)	37/20	**50/68**	**53/42**	**37/39**	**41/33**

Percentage of answers of alternative explanations per question within the main categories 1) Confusing mass and density, 2) Believe mass can turn into heat or pressure or vice versa, 3) Mass appears, disappears or substance has no weight. Phase change in an open[1] system and closed[2] system. Number of incorrect answers[3]. Percentage of engineering students/upper secondary school pupils, respectively.

The number of learners (students 53/ pupils 68%) that suggested that *mass was either created or could disappear* was highest on the question concerning dissolving sugar in water. The majority of answers here suggested that mass disappears. *The disappearing of mass or substance has no weight* was also the most common alternative explanation for the questions concerning combustion and evaporation, where 37/39% used these alternative explanations. For the question concerning decarbonation, the most common alternative explanation (41/33%) was that substances in gaseous state have no weight or mass disappears.

The majority of the students and pupils who showed alternative explanations as to why the weight changes during phase change in a closed system confused the concepts of mass and density.

To the question of what happens when ice melts in a sealed container, many answered that the weight changed since the density changed.

> *"Ice and water have different density, which causes the weight to change and changed its density." "ρ = m/V, V changes which affects mass." "The density in ice is 1 kg/dm^3, for water it is 0.998 kg/dm^3 so it should have decreased. But no matter has left because the lid is closed."*

Changes in density were also used in explanations concerning evaporation in closed systems and gas formation during combustion in closed systems, as well as in the question concerning decarbonation in an open system.

> *"The gas that forms has less density and rises upwards in the bottle." "The phosphorus has reacted with the oxygen that was there and has taken some of the oxygen down into the water, and thereby the density has changed and also the weight has changed." "The carbonic acid in the drink disappears into the air, but makes more room for ordinary air. I don't know the difference between the density of the carbonic acid and the density of the air." "The carbon dioxide is exchanged for air. The density is important for weight change."*

Density was used to explain weight change when sugar is dissolved in water.

> *"It is diluted which affects density." "The density of liquid is lower than in the solid materials."*

In some of the answers, weight change was explained with mass turning into heat and mass turning into pressure. One student used Einstein's formula $E=mc^2$ as an explanation.

> *"Since when the phosphorus ignites, you add energy. And energy has mass ($E=mc^2$), it means that it will weigh more than before."*

Amongst these answers, an increase in pressure is also used as an explanation as to why the weight of the closed container increases.

> *"Gases have less mass. Instead of mass, all of the gas pressure is now on the walls of the container." "Pressure is building, difference in density, higher before and less after." "Freon gas has a higher molecular velocity which causes bouncing on the walls and causes an increase in weight."*

Some of answers contain replies suggesting that mass has been created. For example, the following responses refer to the question concerning the combustion of phosphorus:

> *"If there is a precipitate then it weighs more." "The phosphorus has reacted with the air and that weighs more." "There are other substances formed in the bottle."*

These explanations involve gas being seen as not having weight or the gas molecules being seen as weighing less, but also that liquid and solid phases have different weights.

> *"The phosphorus is now in gaseous form and weighs less." "Some of the Freon will be in the air and therefore the scale won't feel its mass." "Ice is lighter than water." "Water in solid state weighs more."*

Explanations for the mass disappearing when sugar was added to the water were mainly due to the sugar disappearing or at least partially disappearing when dissolved.

> *"Some of the sugar will be bonded to the water." "Because the sugar is dissolved and becomes a part of the water it makes a 'sugar water', but not as much as 200 g extra as it transformed into liquid." "Small amounts of sugar and water can disappear in the transfer." "The water absorbs the sugar and the weight becomes the same as the water (all sugar has dissolved). Regardless of the amount of sugar poured in, the weight remains the same unless there is precipitation."*

Another clue for why students suggest that mass disappears was found when analysing their explanations as to why they believed that weight remains the same when gas diffuses out of an open system. Here air was not seen as having weight, and since the carbonic acid diffused into the air, the students equated the carbonic acid with the air.

"Air has no weight." "The carbonic acid has no weight." "The carbonic acid has left the bottle, but it doesn't matter since it is air."

Answers concerning why the weight remains unchanged when the soda is decarbonated can be connected to gases being weightless.

"The bubbles are oxygen." "Nothing has gone." "Nothing disappears into the air."

The alternative conceptions used by both students and pupils when predicting possible changes in weight were mainly due to a mix-up between the concepts of mass and density (see Table 4). This mix-up was more widespread amongst the students. However, an interesting example was the question regarding evaporation of Freon. Eleven percent of the students suggested that mass can be changed into heat or pressure. None of the pupils used this alternative conception.

V. DISCUSSION

All types of learning are seen here as including social, cultural and individual factors [1]. The individual aspects of learning depend on what the person focuses on and how he/she interprets the content. For the daily practice of engineers, it is important to have a scientific foundation for everyday problem-solving and to derive new creative solutions to practical issues, especially since the everyday problems of engineers today include environmental issues such as global warming, spreading of substances, use of limited resources and issues of recycling. Having a scientific understanding of the particulate nature of matter together with fundamental laws, such as the preservation of mass during physical and chemical change together with the laws of thermodynamics, is essential for all of the above purposes.

Educational issues

Students are thus expected to understand and know how to implement the first law of thermodynamics, but the number of correct answers from the engineering students was only slightly higher than that for the upper secondary school pupils, suggesting that basic conceptual understanding is not a target for education within courses for this educational level and educational focus. Results also show that many of the engineering students struggle to apply their conceptual knowledge to everyday problem-solving [10], [14]–[16]. This type of compartmentalisation of knowledge and lack of conceptual change may stem from the fact that learning is not an expansion of everyday experiences, but instead an addition of knowledge that is not associated with the usual array of knowledge that we naturally draw upon on a daily basis.

Other possible reasons for the results shown here may be that basic concepts have not had time to become entirely established during the upper secondary school years or that there is a lack of progression between different courses, especially progression for developing earlier simplifications, such as early physics lessons where the mass of the air and the friction of the air are neglected in teaching. Fewer upper secondary students used density as an explanation for changes in weight during evaporation, dissolving and combustion. This may be explained by their recent exposure to the concept of density. At the same time, density was used for explaining weight change during melting which suggests that the concept of density was not yet fully developed. One of the possible reasons for the mix-up between energy and mass can be the increase use of physical formulas, such as $E=mc^2$, a formula that can be easily misapplied to systems where the change in mass is neglectable.

Learner's focus

Another way of looking at these answers may be found by thinking of the learning process as dynamic refractions of content instead of reflections. This way of viewing learning suggests that it is important to derive students' previous interpretations of content or lack of interpretations of content before introducing new material. Indeed, engineering students hold many of the same alternative conceptions as younger students [14].

Some of the answers also suggest that the students have difficulties defining the system, *i.e.*, including the limitations of everyday problems in their explanations, which suggests that dimension analysis needs to be further included into problem-solving as well as direct teaching of which changes are negligible or not.

Teaching strategies

Scientific research has already shown students failure to appreciate the meaning of a numerical value in an arithmetic procedure [26], [31]–[33] and the results presented here reinforce this finding. These results support the suggestion that both teachers and learners unintentionally develop an imbalance between their focus on conceptual understanding and algorithmic problem-solving, leading to problem-solving on a mathematical basis rather than on a conceptual basis.

Despite the research literature has described students' difficulties with various aspects of science content, these difficulties and suggested causes for them have not been successfully implemented in practical teacher training. This may be especially evident for engineering teachers, since they commonly have a lot of practical experience but little teacher training within their respective fields.

These results support previous research that stress the importance of repeating concepts [24], [25] and of not taking previous education as a guarantee for conceptual understanding. Particularly because concept formation requires time to obtain, extending the amount of time for learning becomes an important consideration. Shorter paths towards higher education study may contribute to less qualified students.

Limitations of the study

Some of the results in this study may be due to the students not wanting to work actively with the questions, and therefore just providing a response without much reflection and instead reverting to earlier alternative conceptions. Notably, if student explanations would have been collected through an interview study, the explanations could have been further explored.

VI. CONCLUSION

The results show the importance of analysing students' explanations in order to develop their conceptual understanding by re-addressing scientific concepts continuously so that the scientific concepts become the natural foundation for explanations. The need for increasing the students' analytical skills is also apparent in the results. Some of the students did not initially define the limits of the system at hand, which is essential for problem-solving. Another part of problem-solving includes a correct assessment of the physical quantities of numerical outcomes. The time requirements to obtain conceptual formation become especially important for discussions concerning a broadened student recruitment. Changes in prerequisites for university level education may lead to students who have less understanding for fundamental concepts and thereby contribute to a reduction of the quality of higher education.

APPENDIX

The research-based questions

The first item was a multiple-choice question which asked: What has weight? A series of everyday things, for example heat and air, were included together with the choice of answering yes or no.

The remaining items were also multiple-choice questions, but they included images and an additional open-ended request: Would you explain your answer? These questions and the included images are presented in Figure 1.

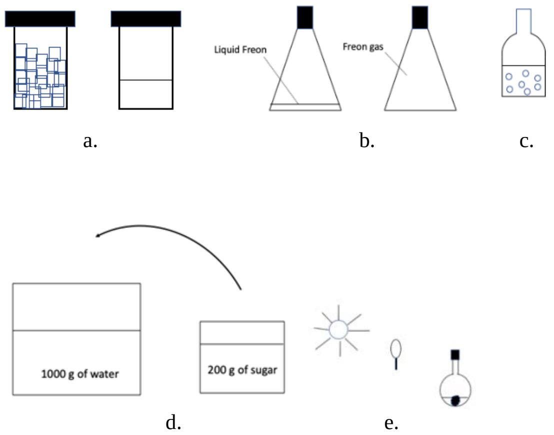
The first question was posed as follows: A cannister is filled with ice cubes (Figure 1a). A lid is placed on the cannister to seal the system, and the cannister is weighed. The result is 630 g. The cannister is then left until all of the ice has melted, and then it is weighed again. What is the result of the second weighing? Students were to select one multiple-choice answer: much more than 630 g, a little more than 630 g, 630 g, less than 630 g, or a lot less than 630 g. There was also the statement, 'please explain your answer'.

The second question was posed as follows: A sealed flask contains liquid Freon (Figure 1b). The flask is weighed on a scale, then the Freon is left to evaporate, and the flask is weighed again. What is the result of the second weighing? Students were to select one multiple-choice answer: less than when it was weighed the first time, more than it was weighed the first time, or the same as the first time it was weighed. There was also the statement, 'please explain your answer'.

The third question was posed as follows: An open bottle of carbonated soda is weighed (Figure 1c). The bottle is then shaken, but no liquid is spilled out. Many bubbles are formed; the bubbles rise through the liquid and burst at the surface. The shaking of the bottle is repeated several times until there are almost no bubbles left. The bottle is weighed again. What is the result? Students were to select one multiple-choice answer: the bottle weighs more than before, as much as it did before, or less than before. There was also the statement, 'please explain your answer'.

The fourth question was posed as follows: In a container there are 1000 g of water. 200 g of sugar is dissolved in the water (Figure 1d). What does the content of the container weigh after the sugar is dissolved? Students were to select one multiple-choice answer: less than 1000 g, 1000 g exactly, between 1000-1200 g, exactly 1200 g, or more than 1200 g. There was also the statement, 'please explain your answer'.

The fifth question was posed as follows: A sealed flask containing phosphorus and water was weighed to 205 g (Figure 1e). The phosphorus was ignited, and the smoke dissolved in the water. After the bottle had cooled down, the flask was weighed again. What did it weigh? Students were to select one multiple-choice answer: more than 205 g, 205 g, or less than 205 g. There was also the statement, 'please explain your answer'.



a. b. c.

d. e.

Fig. 1. Images symbolising a. a sealed cannister of ice before melting and the liquid water after melting. b. a sealed flask of liquid Freon before evaporation and after evaporation. c. an open bottle of carbonated soda. d. an open system with a cannister containing 1000 g of liquid water and a cannister containing 200 g of sugar. e. a sealed flask containing liquid water and a piece of solid phosphorus. A magnifying glass and the sun. Adapted from Andersson et al. 2003 [37].

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REFERENCES

[1] N. Veresov, 'The Concept of Perezhivanie in Cultural-Historical Theory: Content and Contexts', in *Perezhivanie, emotions and subjectivity: advancing Vygotsky's legacy*, M. Fleer, F. L. González Rey, and N. Veresov, Eds. Singapore: Springer, 2017, pp. 47–70.

[2] A. Ayas, H. Özmen, and M. Çalik, 'Students' Conceptions of The Particulate Nature of Matter at Secondary and Tertiary Level', *International Journal of Science and Mathematics Education*, vol. 8, no. 1, pp. 165–184, 2010, doi: 10.1007/s10763-009-9167-x.

[3] A. García Franco and K. S. Taber, 'Secondary Students' Thinking about Familiar Phenomena: Learners' explanations from a curriculum context where "particles" is a key idea for organising teaching and learning', *International Journal of Science Education*,

vol. 31, no. 14, pp. 1917–1952, 2009, doi: 10.1080/09500690802307730.

[4] E. Kikas, ‘Teachers’ conceptions and misconceptions concerning three natural phenomena’, *Journal of Research in Science Teaching*, vol. 41, no. 5, pp. 432–448, 2004, doi: 10.1002/tea.20012.

[5] M. B. Nakhleh, ‘Why some students don’t learn chemistry: Chemical misconceptions’, *Journal of Chemical Education*, vol. 69, no. 3, pp. 191–196, 1992, doi: 10.1021/ed069p191.

[6] K. S. Taber, ‘Alternative Conceptions and the Learning of Chemistry’, *Israel Journal of Chemistry*, vol. 59, no. 6–7, pp. 450–469, 2019, doi: 10.1002/ijch.201800046.

[7] Bell, D. *et al.*, ‘Working with Big Ideas of Science Education’, W. Harlen, Ed. 2015.

[8] National Research Council, ‘Next Generation Science Standards: For States, By States’, National Academies Press, Washington, D.C., Aug. 2013. doi: 10.17226/18290.

[9] A. G. Harrison and D. F. Treagust, ‘The particulate nature of matter: Challenges in understanding the submicroscopic world’, in *Chemical education: Towards research-based practice*, In J. K. Gilbert, O. De Jong, R. Justi, D. F. Treagust and J. H. Van Driel. Eds., Dordrecht: Kluwer, 2002, pp. 189–212.

[10] F. Flores-Camacho, L. Gallegos-Cázares, A. Garritz, and A. García-Franco, ‘Incommensurability and Multiple Models: Representations of the Structure of Matter in Undergraduate Chemistry Students’, *Science & Education*, vol. 16, no. 7, pp. 775–800, 2007, doi: 10.1007/s11191-006-9049-3.

[11] J. K. Gilbert and D. F. Treagust, ‘Introduction: Macro, Submicro and Symbolic Representations and the Relationship Between Them: Key Models in Chemical Education’, in *Multiple Representations in Chemical Education*, J. K. Gilbert and D. Treagust, Eds., 4 vols, Milton Keynes, UK: Springer, 2009, pp. 1–8.

[12] A. H. Johnstone, ‘Macro- and micro-chemistry’, *School Science Review*, vol. 64, pp. 377–379, 1982.

[13] V. Talanquer, ‘Macro, Submicro, and Symbolic: The many faces of the chemistry “triplet”’, *International Journal of Science Education*, vol. 33, no. 2, pp. 179–195, 2011, doi: 10.1080/09500690903386435.

[14] B. Andersson, ‘Pupils’ conceptions of matter and its transformations (age 12-16)’, *Studies in Science Education*, vol. 18, no. 1, pp. 53–85, 1990, doi: 10.1080/03057269008559981.

[15] L. M. Hartley, B. J. Wilke, J. W. Schramm, C. D’Avanzo, and C. W. Anderson, ‘College Students’ Understanding of the Carbon Cycle: Contrasting Principle-Based and Informal Reasoning’, *BioScience*, vol. 61, no. 1, pp. 65–75, 2011, doi: 10.1525/bio.2011.61.1.12.

[16] K. Salta and C. Tzougraki, ‘Conceptual Versus Algorithmic Problem-solving: Focusing on Problems Dealing with Conservation of Matter in Chemistry’, *Research in Science Education*, vol. 41, no. 4, pp. 587–609, 2011, doi: 10.1007/s11165-010-9181-6.

[17] O. Lee, D. C. Eichinger, C. W. Anderson, G. D. Berkheimer, and T. D. Blakeslee, ‘Changing middle school students’ conceptions of matter and molecules’, *Journal of Research in Science Teaching*, vol. 30, no. 3, pp. 249–270, 1993, doi: 10.1002/tea.3660300304.

[18] G. Nicoll, ‘A report of undergraduates’ bonding misconceptions’, *International journal of science education*, vol. 23, no. 7, pp. 707–730, 2001, doi: 10.1080/09500690010025012.

[19] S. Novick and J. Nussbaum, ‘Junior High School Pupils’ Understanding of the Particle Nature of Matter: An Interview Study’, *Science Education*, vol. 62, no. 3, pp. 273–281, 1978.

[20] S. Novick and J. Nussbaum, ‘Pupils’ understanding of the particulate nature of matter: A cross-age study’, *Science Education*, vol. 65, no. 2, pp. 187–196, 1981, doi: 10.1002/sce.3730650209.

[21] H. Goldring and J. Osborne, ‘Students’ difficulties with energy and related concepts’, *Physics Education*, vol. 29, no. 1, pp. 26–32, 1994, doi: 10.1088/0031-9120/29/1/006.

[22] E. Tatar and M. Oktay, ‘Students’ Misunderstandings about the Energy Conservation Principle: A General View to Studies in Literature’, *International Journal of Environmental & Science Education*, vol. 2, no. 3, pp. 79–81, 2007.

[23] R. Trumper, ‘The need for change in elementary school teacher training: the case of the energy concept as an example’, *Educational Research*, vol. 39, no. 2, pp. 157–173, 1997, doi: 10.1080/0013188970390204.

[24] M. Çalik, ‘A Cross-Age Study of Different Perspectives in Solution Chemistry from Junior to Senior High School’, *International Journal of Science and Mathematics Education*, vol. 3, no. 4, pp. 671–696, 2005, doi: 10.1007/s10763-005-1591-y.

[25] S. Rahayu and M. Kita, ‘An Analysis of Indonesian and Japanese Students’ Understandings of Macroscopic and Submicroscopic Levels of Representing Matter and Its Changes’, *International Journal of Science and Mathematics Education*, vol. 8, no. 4, pp. 667–688, 2010, doi: 10.1007/s10763-009-9180-0.

[26] G. M. Bodner, ‘I Have Found You an Argument’, *Journal of Chemical Education*, vol. 68, no. 5, p. 385, 1991.

[27] A. H. Haidar, ‘Prospective Chemistry Teachers’ Conceptions of the Conservation of Matter and Related Concepts’, *Journal of Research in Science Teaching*, vol. 34, no. 2, pp. 181–197, 1997, doi: 10.1002/(SICI)1098-2736(199702)34:2<181::AID-TEA5>3.0.CO;2-P.

[28] R. S. Treptow, ‘E = mc2 for the chemist: When is mass conserved?’, *Journal of Chemical Education*, vol. 82, no. 11, pp. 1636–1641, 2005, doi: 10.1021/ed082p1636.

[29] S. Agung and M. S. Schwartz, ‘Students’ Understanding of Conservation of Matter, Stoichiometry and Balancing Equations in Indonesia’, *International Journal of Science Education*, vol. 29, no. 13, pp. 1679–1702, 2007, doi: 10.1080/09500690601089927.

[30] H. Özmen and A. Ayas, ‘Students’ difficulties in understanding of the conservation of matter in open and closed-system chemical reactions’, *Chem. Educ. Res. Pract.*, vol. 4, no. 3, pp. 279–290, 2003.

[31] S. J. Hawkes, ‘The concept of density’, *Journal of Chemical Education*, vol. 81, no. 1, pp. 14–15, 2004, doi: 10.1021/ed081p14.

[32] A. B. Arons, *Teaching introductory physics*. New York: Wiley, 1997.

[33] J. Surif, N. H. Ibrahim, and S. F. Dalim, ‘Problem Solving: Algorithms and Conceptual and Open-ended Problems in Chemistry’, *Procedia - Social and Behavioral Sciences*, vol. 116, pp. 4955–4963, 2014, doi: 10.1016/j.sbspro.2014.01.1055.

[34] G. M. Bodner and J. D. Herron, ‘Problem-solving in chemistry’, in *Chemical Education: Towards Research-based Practice*, J. K. Gilbert, O. De Jong, R. Justi, D. F. Treagust and J. H. Van Driel, Eds., Dordrecht, The Netherlands: Kluwer academic publisher, 2002, pp. 235–265.

[35] K. C. D. Tan, N. K. Goh, L. S. Cia, and D. F. Treagust, ‘Linking the Macroscopic, Sub-microscopic and Symbolic Levels: The Case of Inorganic Qualitative Analysis’, in *Multiple Representations in Chemical Education*, J. K. Gilbert and D. Treagust, Eds., 4 vols, Milton Keynes, UK: Springer, 2009, pp. 137–150.

[36] S. Vosniadou and I. Skopeliti, ‘Evaluating the effects of analogy enriched text on the learning of science: The importance of learning indexes’, *Journal of Research in Science Teaching*, vol. 56, no. 6, pp. 732–764, 2018 2019, doi: 10.1002/tea.21523.

[37] B. Andersson *et al.*, ‘Att förstå naturen - från vardagsbegrepp till kemi sex “workshops”’, Göteborgs universitet, Insitutionen för pedagogik och didaktik, Göteborg, 2003.

[38] B. Andersson, ‘Chemical reactions’, Göteborgs universitet, Institutionen för Praktisk Pedagogik, Göteborg, 1984.

[39] B. Andersson, ‘Materia och dess transformationer’, Göteborgs universitet. Institutionen för pedagogik, Göteborg, 1989.

[40] B. Andersson and F. Bach, ‘Att utveckla naturvetenskaplig undervisning. Exemplet gaser och deras egenskaper’. NA-spektrum: Studier av naturvetenskapen i skolan, Göteborgs universitet, Institutionen för didaktik och pedagogisk profession, 1995.