Investigation of teacher-candidates' level of knowledge and their misconceptions with content analysis

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Contents

Abstract

This study aims to determine the challenges faced by mathematics teacher-candidates on unit conversion and dimensional analysis. The research was conducted using content analysis method of qualitative research methods. The study group consists of 66 people, 50 females and 16 males, elected through appropriate sampling method, studying at state university in the academic year of 2015-2016. Five open-ended questions were used, prepared by researchers also utilising from the technical literature for the purpose of identifying challenges faced by students during the transfer of mathematical knowledge about unit conversion and dimensional analysis in physics classes. Findings obtained for increasing the validity and reliability of the research were independently coded by each researcher, then these codes were grouped under the same theme of unit conversion and dimensional analysis. Following an investigation on the answers given by students participating in this research, it was determined that they did not have enough knowledge on base quantities within SI unit system and they had problems in transitions between upper and lower coefficients. It was also found that they had misconceptions on the theme of dimensional analysis. Amplitude of mathematical procedures and formulae within physics and the lack of mathematical skills of the students indicates that they suffer an inadequacy in unit conversion and dimensional analysis operations.

Keywords: Base Units, Unit Conversion, Dimensional Analysis, Mathematics, Physics, Misconception

Introduction

Adapting to the rapid developments in information and technology is possible through revising the system of education based on necessities (Acar & Anıl, 2009; DiMartino, Castaneda, Brownstein & Miles, 2007; Bayrak & Erden, 2007; Birgin & Gürbüz, 2008; Sağlam-Arslan, Avcı & İyibil, 2008). Foundations of the education system must include enabling students learn and understand the reason *why and how* they are taught of such information. That would be the sole method for the creation of an efficient and qualified educational atmosphere. Interdisciplinary studies continue to reveal the necessity of qualified and permanent learning. Interdisciplinary teaching is considered to be an efficient strategy towards bringing information and skills together in a meaningful manner. Thus, science and mathematic show importance in interdisciplinary studies.

For students to gain a clear understanding of scientific theories, it is required to construct concepts well in their memories (Wubbels, 1992; Driver et al, 1994). The path of access to information is through concepts. Ability to learn concepts is directly proportional to knowledge depending on students' experiences and their interest in class (Posner et al, 1982; Duit & Treagust, 1995; Hidi, 2006). It is known from the literature that students have some preconceptions from their experiences and a lot of them do not match with the scientific conceptions (Halloun & Hestenes, 1985; McDermott, 1984). Generally, preconceptions can be also named misconceptions, alternative conceptions or alternative framework and the most significant characteristic of misconceptions is that they cannot be overcome by means of conventional instruction (Clement, 1982; van den Berg & Grosheide, 1993; Petersson, 2002; Muthukrishna et al, 1993; Stromdahl, 2002; Andre & Ding, 1991; Caillot & Xuan, 1993).

When the importance of science for the became universally recognized and appreciated, the need for measurements boomed, and the preference for 'universal' standards with it (Pavese & Charki, 2016). International System of Units (SI) is recognized by almost member of the world community, especially the industrially-developed countries (Bimp, 2016). The ease that SI units brought to unit systems is obvious. Units also known as "Basic Units" constitute the basis of SI units. Such units are shown in Table 1 (Güyagüler, 1984; Pavese, 2014).

Table 1. Basic units based on SI.

Base units	**Unit Name**	**Symbol**
Length	Metre	m
Mass	Kilogram	kg
Time	Second	s
Current intensity	Ampere	A
Temperature	Kelvin	K
Matter Amount	Mole	mol
Light intensity	Candela	cd

Tools in measurement systems can be separated into two groups as standards and non-standards. Standard ones have their own units, non-standards do not (Baykul, 2005).

The fact that all information taught in science and math classes are inter-related, reveals itself from every aspect. Accumulation of knowledge and experience of individuals in one field, directly supports other fields (Kaya et al, 2006). Deficient learning in basic math and the lack of adequate transfer of information reveal themselves in sciences but especially in physics. Taking a look at national and international studies, it can be seen that there is a strong relationship between math and physics, as deficiencies create reciprocal negative consequences (Meltzer, 2002; Albe et al, 2001; Tzanakis, 2002; Eryılmaz, 1992; Clement, 1982; Eryılmaz, 1996). In their study conducted in 2009 concerning the opinion of students towards physics class, Alptekin et al. concluded that 90% math knowledge is required to succeed in physics. Gürkan & Gökçe (2002) state that "students dislike science classes as they lack sufficient math knowledge". According to Güzel (2004), there is a close relationship between success in physics and attitude towards math. Specifically, students with better grasp on this relationship have higher success rates. Examining teacher opinion about reasons of liking or disliking science classes by students, Karaer in (2006) found that students fail in science classes as their math knowledge is insufficient. As Karakuyu (2008) states, students can sometimes be unable to perform mathematical operations despite of understanding physics topics containing mathematical operations due to their biases against math classes. Revealing that science teachers are forced to explain math topics instead of physics due to the lack of knowledge in math. Bütüner & Uzun (2011) explain teachers participating in that study claim that math-based deficiencies during Science and Technology classes result in loss of time, impaired performance and motivation.

During the education period, basic concepts determine the strong relationship between mathematics and sciences and the basis of concepts is constituted by units and constants. Since units of quantitative measurement are needed in almost any human activity, it is important that all scientists and practitioners have correct information and understanding of them (Pavese & Charki, 2016). These deficiencies create student failures (Basson, 2002).

In their study conducted in 2001 for measuring whether high school students learnt constants, symbols and units related to concepts taught in high school chemistry, Yücel et al revealed that students did not efficiently or adequately learn constants, symbols and units related to concepts.

According to the Board of Education and Discipline of Turkish Ministry of National Education; student awareness of scientific knowledge development and the properties of physical quantities are emphasized to be the goal of physics. Other goals are to make students see the relationship between physics, other scientific fields and technology, as well as develop positive values towards the science of physics. Students are expected to convert mass and volume units within the chapter of matter and density; meanwhile comparing and converting heat and temperature units within the chapter of heat, temperature and internal energy (M.E.B., 2013).

In studies that investigated the difficulties of students related to many physics subjects, difficulties were directly or indirectly identified based on questions and observations. Although there are little studies in the literature dealing with difficulties experienced by students in units (Kaplan et al., 2014; Yıldırım & İlhan, 2007; Yücel et al., 2001), there is no study that investigates to dimensional analysis.

Methodology

Research Model

Qualitative research method was preferred for this research as the researcher undertakes the role of participator, demonstrates a holistic approach, facilitates easy reveal of perception, and as the research holds a pattern of flexibility and inductive analysis. Qualitative researches employ the attempt of studying, identifying and understanding conditions, social facts, norms and values (Yıldırım & Şimşek, 2008). Content analysis model of qualitative research method was preferred in this study, as the main purpose is to identify levels of knowledge and misconceptions of mathematics teacher-candidates on unit conversion and dimensional analysis in physics classes. Yıldırım & Şimşek (2008) also refer to the purpose of content analysis as achieving concepts and relationships that can explain the data collected. It is required to conceptualize the data collected at first, then organize them in a logical way in accordance with the concepts emerged, and therefore to identify the themes that explain meanings of the data. There are four steps, such as processing qualitative research data obtained from documents, coding data and identifying themes, organizing the codes and themes, describing the findings and their interpretation (Yıldırım & Şimşek, 2008; Miles & Huberman, 1994). Also in this study, encoding operations were performed based on the elected criteria and screening, and then various themes were achieved. After this stage the data were arranged, grouped by themes, and presented numerically where appropriate. Finally, comments on findings were presented.

This research was conducted for the purpose of determining knowledge conditions on Unit Conversion and Dimensional Analysis of a total of 66 university students, 50 of which were females and 16 males, all of whom studied at state university for the summer period of 2015-2016 academic year.

Data collection

A questionnaire consisting of (5 open-ended questions) 3 unit conversion and 2 dimensional analysis, was used as a data collection tool, by also utilizing from the technical literature (Kaplan et al, 2014; Serway & Jevett, 2000). Other than the participants, questions prepared were also offered for the consideration of two expert lecturers from physics and mathematics teaching so as to ensure the suitability and validity in terms of content and purpose.

Data analysis

The findings of the research were obtained with an open-ended questionnaire. Questions are grouped in a way that consists of units and dimension analysis themes. Student responses and remarks were encoded by researchers separately, then grouped unanimously to be analyzed as full understanding (FU), partial understanding (PU), misunderstanding (MU), and not understanding (NU) (Abraham et al, 1994).

Responses given by the candidate teachers were put into qualitative analysis through open encoding method, while codes were supported with direct quotes from students' words. While quoting directly from students' words, students were numbered respectively and considering the gender factor the letters (F) for female and (M) for male were put before the numbers.

Results

This section includes data obtained from themes of unit conversion and dimensional analysis collected from 66 students participating in this research.

Theme 1: Unit conversion

A unit conversion expresses the same property as a different unit of measurement. A conversion factor is a number used to change one set of units to another, by multiplying or dividing. When a conversion is necessary, the appropriate conversion factor to an equal value must be used (firefightermath.org).

On Table 2; the question "**Is it correct that a constant quantity does not have a unit**? Explain your answer" is given together with the analysis of responses from mathematics teacher-candidates.

Table 2. Analysis of responses related to unit of constant quantity.

Comprehension Level	Encoding	f	%
FU	A constant quantity can have a unit	-	-
PU	Constant quantities have units. Accurate sampling on the subject	6	9.09
	Constant quantities do not have units. Accurate sampling on the subject	1	1.52
MU	Constant quantities have units. Inaccurate sampling on the subject	45	68.18
	Constant quantities do not have units. Inaccurate sampling on the subject	11	16.67
NU	Unanswered	3	4.54

None of the prospective teachers could reply to the first question. 10.61% of prospective teachers were able to answer with positive or negative responses, all of which were wrong, exemplifying their responses. The candidate teacher numbered [F40] responded with partial understanding as: "*Wrong. Unit of the line constant "k" is*$=>F=kx^2=>N/m^2$". The question was both exemplified and answered incorrectly with the rate of 84.85%. When misconceptions are cited, they are often given one-sentence characterizations, as in the above (Capper, 1984). Such a sentence seems to presuppose the weaker sense of restructuring because the misconceptions are characterized simply as false beliefs that are highly resistant to tuition (Carey, 1986). Teacher candidate numbered [F23] replied the question as: "*Wrong. Despite energy being a constant quantity, it has its unit which is joule.*", Teacher candidate numbered [F32] replied the question with misunderstanding as "*Statement wrong. Quantities cover an area in space. Each space has a unit statement for indication.*" Teacher candidate numbered [F23] is in confusion about physical constants having or not having a unit, due to her response referring to conservative energy. Teacher candidate numbered [F32] displays a conceptual delusion by confusing the concept of matter with physical constants based on the word 'quantity' mentioned in the question.

Table 3 shows the analysis of the question "**130 pm= .... m**".

Table 3. Analysis of responses related to conversion of basic units based on powers of ten.

Comprehension Level		Encoding	f	%
FU	↑	$13x10^{-11}$ m	6	9.09
PU		-	-	-
MU		Conversion of lower units	26	39.39
		Conversion of higher units	3	4.54
NU		Unanswered	31	46.97

In this question where mathematical knowledge related to unit conversion between higher and lower units by math teacher-candidates, the level of success is unfortunately very low with the rate of 9.09%. Candidate teacher numbered [M7] responded the question incorrectly as "*130 pm=……13.10^{-8}m*"; while also another candidate teacher numbered [M14] responded incorrectly as "*130 pm= 13.10^{10}m*". If unit conversion information was successfully processed through working memory, it would have held in long-term memory. The transfer of schematic knowledge from controlled to automatic processing is another important factor in learning (Schneider & Shiffrin, 1977; Shiffrin & Schneider, 1977).

Table 4 demonstrates answers to the question "**What is the density (g/cm^3) of a spherical object with a radius of 1x10^2 µm, mass of 3x10^{19}mg?**"

Table 4. Analysis of responses related to expression by a restricted unit of another unit.

Comprehension Level		Encoding	f	%
FU	↑	$(9/4\pi)x10^{22}$ g/cm^3	-	-
PU		Not knowledge on volume of a spherical object	1	1.52
MU		Non-converted Units	16	24.24
		Comparison of unit conversions	30	45.45
NU		Unanswered	19	28.79

It can be easily said that math teacher-candidates were unsuccessful in expressing the answer to a restricted unit. The question was answered by a teacher-candidate with partial understanding with correct conversion of units but calculating volume of the spherical object by using $¾\pi r^3$ equation. There were teacher-candidates with the rate of ¼ who preferred to go ahead and calculate without converting the units. Error rate by teacher-candidates during unit conversion is 45.45%.

Theme 2: Dimensional Analysis

The word dimension has a special meaning in physics. It denotes the physical nature of a quantity (Serway & Jevett, 2000). The premise of dimensional analysis is that the form of any physically significant equation must be such that the relationship between the actual physical quantities remains valid independent the magnitudes of the base units. Quantities that are clearly physically different (e.g. work and torque) may have the same dimension (Sonin, 2001).

Table 5 demonstrates the analysis of the question "**A parachutist jumping from a plane is imposed to an air drag of $\vec{F} = -A.\vec{v}$. What is the dimension of the constant ?** Explain your answer. "

Table 5. Analysis of responses related to expression by a restricted unit of another unit.

Comprehension Level	Encoding	f	%

FU		$[M][T]^{-1}$ or kg/s	3	4.54
PU		Not knowledge on Rules of Dimensional Analysis	4	6.06
MU		Not knowledge on SI Base Quantities	12	18.18
		No dimension	1	1.52
		One-dimensional	2	3.03
		Three-dimensional	1	1.52
		Equal to gravitational acceleration	1	1.52
		Confusion of dimension with volume	1	1.52
NU		Non-encodable or unanswered	41	62.12

Examining Table 5 shows that the question was answered with full understanding with a rate of 4.54%. During dimensional analysis, the minus in the formula was transferred and the fact symbols have no importance during dimensional analysis did confuse the teacher candidates with a rate of 6.06%. Math teacher-candidates responded the question with misunderstanding with a rate of 27.29%. This question was answered by the teacher-candidate numbered [M12] as "Dimension of the constant A must be equal to the volume of the parachutist", whereas by [M9] as "Dimension of the constant A is equal to gravitational acceleration and constant. Jumping parachutist cannot exceed a certain speed". It is seen that the dimensional analysis does not occur in the teacher-candidate’s existing conceptual framework.

Table 6 includes the question of **"Is the statement true that dimensional analysis can be used for a proportion constant in a mathematical equation?** Explain your answer."

Table 6. Analysis of responses related to the knowledge on dimensional analysis and proportion constants

Comprehension Level		Encoding	f	%
FU	↑	Cannot be used in dimensional analysis	1	1.52
PU		Incorrect explanation of reason	4	6.06
MU		Usable in dimensional analysis	46	69.70
NU		Non-encodable or unanswered	15	22.73

The teacher candidate numbered [F29] answered this question with full understanding as "*Incorrect. Dimensional analysis is related to which unit should the result of a mathematical equation be expressed in*". An incorrect answer from a teacher-candidate is as follows [F4]: "*Usable. As dimensional analysis is performed via units, it has an equivalent within the calculation of proportion constant. Everything can be revealed by dimensional analysis*". The rate of unencodable responses to this question is 22.73%.

Discussion and conclusion

This research uncovers the level of knowledge and misconceptions of summer period state university students on the themes of 'unit conversion and dimensional analysis'. Accordingly, there are no teacher-candidates expressing that a constant quantity can have a unit. However, within the results of a study conducted on senior students at department of physics; Kaplan et al., (2014) predicate the rate of answers to the same questions as 58.06%. Responses by teacher-candidates related to that a constant quantity cannot have a unit, were given with partial or misunderstanding with a rate of 18.19%. When compared, these results show partial resemblance to the results of Kaplan et al., (2014). Success is few or none as can be understood from the analyses of the two unit conversion-themed questions. The rate of misunderstanding of prefixes used in units and their conversion remains at 43.93%. Misunderstanding of the question related to expression of a result in another particular unit was 69.69%. The study conducted for determining the opinion and knowledge of high school students on units in chemistry classes in 2007 by Yıldırım & İlhan brought them to the conclusion that the students had problems and did not know well about units due to 65% negative (disagree +

completely disagree) response results given to the 4th sentence which was "... score should be deducted if the answer in exams does not indicate any unit". Detected at high school level, this ratio is roughly the same at bachelor's degree especially with teacher-candidates. Level of understanding is also very low in the analysis of the other two questions themed dimensional analysis.
Some of the misconceptions uncovered by this research are: conversion through incorrect multiplier during unit conversion, the attempt to reach the result that is asked in a particular unit without performing any conversion operations, lack of knowledge on SI base quantities, confusion of derived quantities with base quantities, use of minus sign during dimensional analysis, and the attempt to determine proportional constants via dimensional analysis.

Considering the results obtained from this study, it can be suggested that classes could employ a quality technique so as to eliminate conceptual delusions due to serious lack of knowledge by math teacher-candidates on units and dimensional analysis, and the presence of various conceptual delusions. Analogies can be used with new learning or to stimulate conceptual change by comparing situations that learners understand to other situations they misunderstand (Stavy, 1991). Cooperative learning is also one instrument for stimulating student-student interactions and learning. Further research on the topic of units is highly recommended due to the short numbers of researches in technical literature under this field.

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Appendix

Dear teacher candidates, this test aims to evaluate your knowledge on ***"unit conversation and dimensional analysis".*** The answers you provide will not have any effect on your course grades. Your answer sheets will be used within the research being conducted, and your name will be kept confidential in accordance with the codes of ethics. For validity of the research, it is very important that you answer all questions. Therefore, please do not leave any question blank. Thank you for your interest, and good luck.

Name & Surname: **Class:**

1. Is it correct that a constant quantity does not have a unit? Explain your answer."

2. 130 pm= .... m.

3. What is the density (g/cm^3) of a spherical object with a radius of 1x10^2 µm, mass of 3x10^{19} mg?

4. A parachutist jumping from a plane is imposed to an air drag of $\vec{F} = -A.\vec{v}$. What is the dimension of the constant ? Explain your answer.

5. Is the statement true that dimensional analysis can be used for a proportion constant in a mathematical equation? Explain your answer.