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Can Definitions Contribute to Alternative Conceptions?: A Meta-Study Approach

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Abstract: There has been disagreement on the importance of definitions in science education. Yager (1983) believes that one crisis in science education was due to the considerable emphasis upon the learning of definitions. Hobson (2004) disagrees with physics textbooks that do not provide general definition on energy. Some textbooks explain that "there is no completely satisfactory definition of energy" or they can only "struggle to define it."

In general, imprecise definitions in textbooks (Bauman, 1992) and inaccuracies in definition provided by teachers (Galili & Lehavi, 2006) may cause alternative conceptions. Besides, there are at least four challenges in defining physical concepts: precision, circularity, context and completeness in knowledge. These definitional problems that have been discussed in The Feynman Lectures, may impede the learning of physical concepts.

A meta-study approach is employed to examine about five hundreds journal papers that may discuss definitions in physics, problems in defining physical concepts and how they may result in alternative conceptions. These journal papers are mainly selected from journals such as American Journal of Physics, International Journal of Science Education, Journal of Research in Science Teaching, Physics Education, The Physics Teachers, and so on. There are also comparisons of definitions with definitions from textbooks, Dictionaries of Physics, and English Dictionaries.

To understand the nature of alternative conception, Lee *et al*. (2010) have suggested a theoretical framework to describe the learning issues by synthesizing cognitive psychology and science education approaches. Taking it a step further, this study incorporates the challenges in semantics and epistemology, proposes that there are at least four variants of alternative conceptions.

We may coin the term, 'alternative definitions', to refer to the commonly available definitions, which have these four problems in defining physics concepts. Based on this study, alternative definitions may result in at least four variants of alternative conceptions. Note that these four definitional problems or challenges in definitions cannot be easily resolved. Educators should be cognizant of the four variants of alternative conceptions which can arise from alternative definitions. The concepts of alternative definitions can be useful and possibly generalized to science education and beyond.

Key words: Definitions, Alternative conceptions, meta-study

I. Introduction

There has been disagreement on the importance of definitions in science education. Yager (1983) believes that one crisis in science education was due to the considerable emphasis upon the learning of words, terminologies or definitions. Hobson (2004) disagrees with sixteen introductory physics textbooks, which do not provide general definition on energy. Some textbooks explain that "there is no completely satisfactory definition of energy" or they can only "struggle to define it." Moreover, Rossing (1995) explained that the lack of understanding of magnetic forces can be due to the confusion in terminology and definitions that exists in our physics courses and textbooks.

In general, imprecise definitions in textbooks (Bauman, 1992) and inaccuracies in definition provided by teachers (Galili & Lehavi, 2006) may cause confusions, or alternative conceptions. Besides, there are at least four challenges in defining physical concepts: precision, circularity, context and completeness in knowledge (Wong & Yap, 2010). These definitional problems that have been discussed or mentioned in *The*

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Feynman Lectures, for example, may impede the learning of physical concepts and possibly result in alternative conceptions.

To illustrate how definitions may result in alternative conception, and possibly problem solving, here is one interesting question: What is the buoyant force on a book which is at rest on a table top? In some venerable textbooks (e.g. Halliday *et al.* 2005; Sears, 1950), the buoyant force is defined to be "*upward and has a magnitude equal to the weight of the fluid that has been displaced by the body.*" If teachers adopt this definition on buoyant force, then one would calculate the weight of the air displaced. Hence, some physics education researchers (e.g. Hestenes *et al.*, 1992; Redish, 2003) and teachers suggest that as long as an object is submerged in the fluid or air, there will be buoyant force. Students who provide the answer that there is no buoyant force can be penalized or considered to have alternative conception (Harper, 2003; Hudson & Munley, 1996).

On the other hand, one may include the 'cause' of buoyancy in the definition of the buoyant force: *the upward force on an object produced by the surrounding fluid* (i.e., a liquid or a gas) *in which it is fully, or partially immersed, is due to the pressure difference of the fluid between the top and bottom of the object.* With this definition in mind, one would need no calculation, and deduce that the correct answer is no buoyant force. As there is no fluid below this book, there is no net upward force due to the pressure difference of the fluid. Nevertheless, there is still an upward force, which is due to the normal (contact) force, or reaction force. One may now explain that the students, who calculate the buoyant force using the weight of the fluid displaced, have alternative conception.

The issues on definitions may not be easily resolved as there are disagreements on many definitions, such as heat (Slisko & Dykstra, 1997). Zemansky (1970) preferred to define heat as a noun, that is, heat is the 'energy' transferred because of temperature difference. One alternative conception identified by him was "heat could be stored in a body". This can be attributed to the common usage of language such as heat absorbed (Shaw, 1969). Some physicists may prefer heat to be defined as a process, verb or adjective (Baierlein, 1994; Romer, 2001). For example, heat can be defined as 'transfer' of energy because of temperature difference. Based on this definition, teachers who conceive heat as a form of energy are considered to have alternative conception.

Although Zemansky's definition on heat was considered by many as the 'correct' conception in the 1970s, it can be explained to be an alternative conception (Romer, 2001). However, some textbook authors still prefer to define heat as a noun (e.g. Hecht, 2003; Wilson, Buffa & Lou, 2007). Furthermore, some may prefer to define heat as an interaction (Helsdon, 1976). Hence, there is subjectivity in determining 'alternative conception' for physical concepts when there is no consensus on the correct definition.

If we teach students with 'simple definition' of energy as "the ability to do work" (Papadouris & Constantinou, 2010), they may develop 'naïve' conception. Thus, it is not a surprise that students conceive energy as a form of substance (Warren, 1983). If students are provided with an 'abstract definition': "Energy is *not* concrete; it is *not* a material substance; it is given meaning through the calculation of numbers" (Arons, 1999), they may have sophisticated conception of energy. Students may not conceive energy as material substance if they remember this definition, which specifies the ontological category of energy. The examples on the possible effect of definitions are far from exhaustive. It warrants a meta-study on whether definitions can contribute to alternative conceptions.

Ⅱ. Literature Review

There is no agreement on whether 'alternative conception', 'alternative conceptual frameworks', 'misconceptions', 'naive beliefs', 'naïve' theories', or 'intuitive beliefs' is the most appropriate terminology in science education (Brookes & Etkina, 2009). There is also no agreement on the definition of 'alternative conception'. One of the definitions on alternative conceptions is "*the students' existing ideas and beliefs may be significantly different from accepted scientific viewpoints*" (Palmer, 2001). However, as discussed earlier, there may not be consensus on definition or scientific knowledge. We propose to define alternative conception as *a knowledge structure that is activated in a wide variety of contexts, and is in disagreement with accepted scientific knowledge within a community; the scientists from other communities may not have consensus on this accepted scientific knowledge*. This definition of alternative conception is slightly modified from Redish's (2004) definition of misconception because different communities in Science, such as Biology, Chemistry and Physics, may have different accepted scientific knowledge and definitions. In addition, it is common within physics community to have different preference on the definitions of physical concepts (Slisko & Dykstra, 1997; Swendsen, 2011).

There can be advantages for alternative conception to be broadly defined, to include all kinds of 'misconceptions' during the learning process. However, it can also be useful to be specific in what way the alternative conceptions are 'alternative'. To have deeper understanding, we will explain how the problems of definition may result in variants of alternative conceptions. Note that these definitional problems are not due to carelessness of physicists and textbook authors, but they can be inherent limitations of definitions. These problems can be useful knowledge for physicists, teachers and students. Interestingly, many of these problems have been discussed in *The Feynman Lectures* (Wong & Yap, 2010). We will discuss the literature on the four problems of definitions followed by a framework on alternative conception.

1. The Problems of Definitions

Firstly, Feynman *et al*. (1963, Vol I, 5-1) observed that, "Webster defines 'a time' as 'a period', and the latter as 'a time', which doesn't seem to be very useful." This problem of definition can be coined as the 'problem of circularity' as the two concepts are defined in terms of each other. This problem of circularity was highlighted by Mach as pseudo-definition, and described to be wholly unnecessary tautology (Mach, 1883). Galili and Lehavi (2006) coin the above problem as 'cyclic definition', which points to the failure in applying logic. In their research study, as many as forty-seven percent of the teachers defined *electric charge* as the cause of electric field (force); their standard definition of a *electric field* is based on the concept of *electric charge*.

Secondly, precision is another common problem of definition. Although Feynman explained the necessity to define physics concepts precisely, he disagreed with the philosophers that words must be defined with extreme precision (Feynman, 1998, p. 20). For example, it is formidable to define a chair precisely, say which atoms are chair, and which atoms are air, or which atoms are dirt (Feynman *et al*., 1963, Vol I, 12-2); definition should be as precise as *reasonable*. However, imprecision in definition is also a problem for students and teachers. For example, Taber (2000) preferred to define temperature as "average kinetic energy of the molecules" instead of "concentration of heat energy" (Carlton, 2000). Some may prefer another precise definition: "Temperature is a measure of the average internal molecular kinetic energy of an object" (Tipler & Mosca, 2004). This challenge of defining a more precise physical concept can be known as the 'problem of precision'.

The third definitional problem is context. One should take note that temperature, for example, can be defined differently depending on the context. The word 'context', for example, has more than 150 definitions (Bazire & Brezillon, 2005) depending on the context. Words that have many technical meanings are theory-laden, can differ significantly from their daily definitions or technical context. For example, momentum is defined in the Oxford Dictionary as the "impetus gained by a moving object". In Mechanics, momentum is defined as the product of mass and velocity, but in Quantum Mechanics, momentum is measured by the number of waves per unit length (Feynman *et al.*, 1963, Vol I, 10-9).

The problems of context in definitions can also be present across different subjects. For example, the word, 'molecule', can have different meanings (Williams, 1999) in physics and chemistry. The multiple meanings of the same word can be confusing to students could also be explained by the different definitions of the word, 'mental model'. To elaborate, many educators have defined mental model differently (Lee *et al.*, 2005a); this can also cause confusions and miscommunications among educators. This problem of definition can be described as the 'problem of context'.

Lastly, we should be honest with students on our limited knowledge in physics, just like Feynman, on the definition of energy (Feynman *et al.*, 1963, Vol I, 4-2). This problem of definition is essentially due to the 'incompleteness in knowledge' of current physical concepts. The concept of heat, for example, has been changed over the centuries, and it has been defined as motion, caloric, energy and process (de Berg, 2008). At this moment in time, we cannot be sure if heat will be later preferred to be defined in terms of entropy, for example. Moreover, there is no agreement on the definition of entropy (Swendsen, 2011). Every definition on entropy can be considered to be an alternative conception when there are many different opinions on this definition as the knowledge on entropy is still far from complete.

A definition lacking important features of the concept due to limited knowledge can be considered as incomplete. This is an opportunity for students to learn about the tentative nature of science (Lederman & O' Malley, 1990); that is, scientific conclusions can be modified or replaced. According to Hecht (2006), there seems a prevalent belief within the physics community that the fundamental concepts in physics are well understood and adequately defined. The fact is, whoever has carefully studied the foundational literature in physics over the past centuries, will realize that none of these basic concepts have been satisfactorily defined because of the incompleteness in knowledge either in theory or experiment. Our honesty with students on the problems of completeness in knowledge may also generate interest or curiosity. This challenge of defining a physical concept can be described as the 'problem of completeness in knowledge'.

2. A Theoretical Framework on Alternative Conception

To understand the nature of alternative conception, Lee *et al.* (2005a, 2005b) have suggested a theoretical framework to describe the learning issues by synthesizing cognitive psychology and science education approaches. Mental models are dynamic representations through integrating external information recognized and individual knowledge. This framework can be adapted to explain how definitions can possibly contribute to the alternative conceptions of students (See Fig 1).

In this framework, perception and knowledge are recognized as the main 'input sources' of mental models (Yates, 1985). Mental models are dependent on external information, in the sense that this 'incoming data' can be a stimulus to particular analytical or synthetical subprocesses (Rickheit & Sichelschmidt, 1999). In other words, the 'incoming knowledge on definitions' and the 'awareness on definitional problems' can affect various cognitive processes in learning the physical concepts.

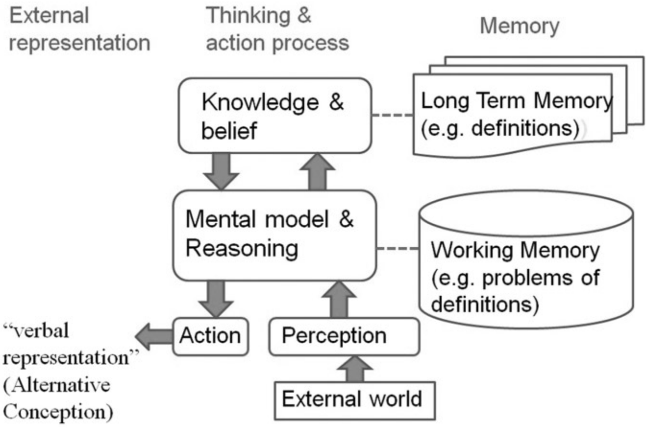


Fig. 1 *The relationships among alternative conception, memory, and mental model in the process of learning. It is adapted from Lee et al.'s (2005a, 2005b) framework.*

The process of learning definitions, concepts and principles by students could be modeled by the use of this framework. Thus, the ability to remember definitions does not imply that students have interpreted them correctly and fully aware of their implication. Besides, when definitions and scientific knowledge are presented to students, they interpret them according to their knowledge and beliefs, which may not be accepted scientific knowledge (or alternative conception).

With the inclusion of the problems of definitions into the framework on alternative conceptions, the following research question is proposed: Can definitions contribute to alternative conceptions? The hypothesis in this research study is *definition may not determine the thinking process, but it may influence the conception or verbal representations of students*. Hence, we hope to establish that while definitions do not necessarily result in alternative conception, it may contribute to students' alternative conceptions because of the problems in definitions.

In general, based on Lee's *et al*. (2005a, 2005b) framework, we propose that students' memory and knowledge of definitions, their belief on nature of science, as well as their perception can contribute to the alternative conceptions of students. In this article, we focus on the 'alternative definitions' and the problems of definitions.

Ⅲ. Methodology

Essentially speaking, meta-research is the synthesis of primary research results into more general conclusions at the theoretical level (Rogers, 1981). In other words, meta-research is the research on research and the analysis of analysis. Thus, meta-study can be defined as a research approach involving analysis of the findings of the qualitative research and synthesis of the researchers' insights into new ways of thinking about phenomena (Paterson *et al*., 2001). This approach has an interpretive, rather than aggregating, in contrast to meta-analysis of quantitative studies.

In this research study, we examine about five hundreds research papers related to definitions in physics, problems in defining physics concepts, or how they may contribute to alternative conceptions. These research papers are mainly selected from *peer-reviewed* journals such as *American Journal of Physics, International Journal of Science Education, Journal of Research in Science Teaching, Physics Education, Science & Education, The Physics*

Teachers, and so on. There are also comparisons of definitions from research papers with selected definitions from 40 introductory physics textbooks, Dictionaries of Physics, and English Dictionaries to suggest how alternative conceptions can be resulted.

Systematic review of papers is selected with the help of databases such as Education Resources Information Center (ERIC). Papers involving fundamental definitions such as mass, weight, force, energy, heat, temperature, electric current, electromotive force (at least 50 journal papers per definition), were searched and studied. To summarize, this analysis is carried out with the following steps:

Step 1. Search is carried out on words, 'define' and 'definition' in these papers.

Step 2. Identify papers that also contain keywords, such as 'circular', 'precise', 'context', and so on, as well as words suggesting similar problems of definitions.

Step 3. Code the papers that contain keywords, for example, circularity or circle as A1. For papers that discuss problems of precision, context, and completeness of knowledge, they will be coded as A2, A3, and A4 respectively.

Step 4. Verify the codes by re-reading the papers to check whether there are any problems of definitions found in these papers. The second author helps to validate the coding; meetings are held to discuss and resolve any disagreement.

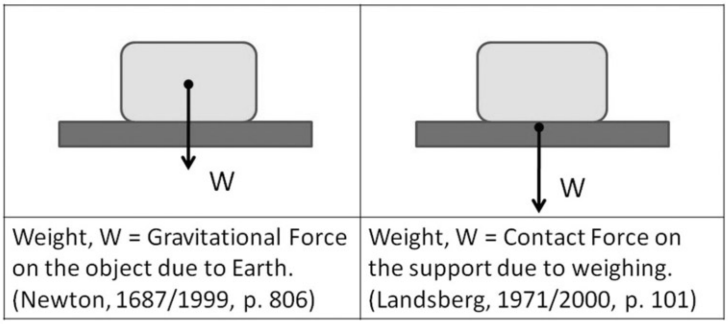
Step 5. Analyze how definitions can possibly result in alternative conceptions.

IV. Results and Discussions

To explain how problems of definitions may have implications in the mental models and result in alternative conceptions, the following discussions mainly utilize the definitions of physical concepts. (Note that these problems of definitions can also be found in other fields, such as biology and chemistry.) We will explain how variants of alternative conceptions may result from four different problems of definitions, namely circularity, precision, context and completeness in knowledge.

1. The Problems of Circularity

One common conceptual definition of weight is the 'force' the Earth exerts on an object. Note that the term, force, may have problem of circularity if one uses Newton's Second Law of motion to define both force and mass (Galili & Lehavi, 2006). On the other hand, if we define weight operationally as "what the weighing scales read", it also has problem of circularity (See Fig 2: Comparison of Conceptual and Operational definitions of Weight). By checking the dictionary, we would find that weighing scale is "a balance used for weighing." In general, defining a physical quantity by the measuring equipment may not help us to conceptualize the nature of this physical quantity. Circularity occurs in this definition because the equipment is defined by the same physical quantity, in



Weight, W = Gravitational Force on the object due to Earth. (Newton, 1687/1999, p. 806)	Weight, W = Contact Force on the support due to weighing. (Landsberg, 1971/2000, p. 101)

Fig. 2 *Comparison of Conceptual and Operational definitions of Weight*

which this equipment is used to measure.

This problem of circularity is surprisingly seldom discussed in current literature. Although operational definition can be useful to physicists who have understood the physical concepts, it may not necessarily add value in learning for novice students. (We do not deny the importance of operational definition.) To ensure everyone communicates and works with the same definition and mental image, we need to conceptualize and operationalize the terminology (Berg, 2009). While operational definitions may not enable students to conceptualize the physical meaning, it is still useful to know how this concept is measurable by the appropriate equipment. For example, with the aid of an ammeter and voltmeter, students may develop operational definitions for the concepts of electric current, potential, potential difference and resistance (Shaffer & McDermott, 1992).

Some studies (Gunstone & White, 1981; Ruggiero *et al*., 1985; Noce *et al*., 1988; Kruger *et al*., 1990) have shown that there is widespread confusion on the concepts of weight and gravity, in different ages of students and primary school teachers. The extent of confusion or alternative conception can be interpreted with different outcomes depending on whether the researchers adopt the definition of weight as 'interaction with Earth' or 'interaction with weighing scale', sometimes known as the operational definition of weight (Galili, 1993). Moreover, Galili and Kaplan (1996) explain that operational definition can develop operational knowledge.

If students' memories on the physical concepts are limited to the given operational definition, their conception of this physical quantity can be essentially operational knowledge with its content and structure. We may describe this kind of conception as 'Operational Conception'. Nevertheless, some may argue that operational definitions, with their problem of circularity, may not deepen our understanding of physical phenomena (Lindsay, 1937) or help to conceptualize the physical quantity (See Table 1).

The problem of circularity is not only restricted to operational definitions. Numerous studies seem to suggest that circularity in definitions can contribute to students' inability to distinguish 'heat and temperature', 'work and energy', 'mass and weight' and 'electric field, electric charge and electric force'. We will briefly discuss these four groups of definitions.

Arnold and Millar (1994) observe that the definitions of heat and temperature are self-referential. In a sense, heat and temperature can both be defined in terms of thermal equilibrium or Zeroth Law of Thermodynamics; essentially, students' memory on the concept of heat involves temperature, and the concept of temperature involves heat. Hence, it may explain why many students are unable to distinguish 'heat' and 'temperature' and the confusion can be attributed to the definitions of the physical concepts (Warren, 1972; Bauman, 1992; Yeo & Zadnik, 2001).

In a similar way, work is sometimes defined as energy transfer, and energy is defined in terms of work; they are defined based on Work-Energy Theorem. Therefore, students' memory of work and energy is closely related, but they may not be able to distinguish work with energy (Driver & Warrington, 1985; Kurnaz & Sağlam-Arslan, 2011). That is, students do not distinguish the meaning of definiendum (e.g. work) and definiens (e.g. energy); they may mix up the meaning of work with the meaning of energy.

It is also reported that students are confused with the concepts of mass and weight (Mullet and Gervais, 1990). The confusion may arise because we measure mass and weight with the same instrument, the weighing scale (Parton, 1975). Essentially, the definitions of mass and weight are related to each other by the same mathematical equation, weight, $W = mg$, m refers to mass and g refers to acceleration due to gravity. Furthermore, it is well established in the engineering literature where physicists' mass is often expressed as W/g (Iona, 1975).

Lastly, electric field has been reported as an

Table 1

Definitions related to Operational Conception

Definitions related to Operational Conception	
Definition of Physical quantity	Definition of Measuring Equipment
Weight *is what bathroom scales read.* (Bishop, 1999) **Weight** is the reading of a spring scale supporting the object, independent of any specification of how the spring scale is supported. (Iona, 1975)	**Scales**: a piece of equipment used for weighing people or things. (Macmillan English Dictionary, 2007) **Spring Balance**: The device is often used to measure the weight of a body approximately. (Oxford Dictionary of Physics, 2005)
Time: The *time of an event* is most naturally defined as the reading on a clock located at the event's position at the instant, at which the event occurs. (Scherr *et al.*, 2001)	**Clock**: system for displaying or recording the passage of time. (Collins internet-linked dictionary of Physics, 2007)
Force: The force is measured by a dynamomter. (Coelho, 2012) The operational definition of **force** employs a spring scale calibrated in newtons. (Karplus, 2003 , p.285)	**Dynamometer**: an instrument used to measure a force, often a spring balance. (Dictionary of Physics, 2005) **Springs** can be used to measure forces. (Karplus, 2003 , p.285)
Temperature is the scale reading on a suitable thermometer. (Harris, 1969) **Temperature** is defined as the reading on a thermometer. (Keyes, 1973)	**Thermometer**: An instrument used for measuring the temperature of a substance. (Oxford Dictionary of Physics, 2005)
Electric Current is measured by the dial reading of a standard ammeter. (Karplus, 2003, p.315)	**Ammeter**: An instrument that measures electric current. (Oxford Dictionary of Physics, 2005)

abstract concept which students have difficulty (Ferguson-Hessler & de Jong, 1987). This could be attributed to the problem of circularity when the definitions of electric field, electric charge and electric force are defined in terms of each other or based on Coulomb's Law. Alternatively, some textbooks will avoid the definition of electric force, but it does not really help. Without defining electric force, student's conception of electric force could be 'anything' and it affects the conception of electric field.

This kind of alternative conception can be coined as 'Mixed Conception' (definiendum and definiens) or indistinguishable conception. Note that definiendum refers to "the term to be defined" and definiens refers to "the terms used in the definitions". Heat and temperature, for example, can both be interchangeably referred to as definiendum and definiens (See Table 2).

Table 2: Definitions related to Mixed Conception (definiendum and definiens)

2. The Problems of Precision

Definitions of physical concepts can be considered to be imprecise if certain features are lacking. To explain the problem of precision, we will discuss the definitions of weight, energy, Newton's third law, and heat respectively. The definition of weight as *the force due to gravity* (Brown, 1999) can be imprecise because it does not specify whether the force is gravitational or electromagnetic in nature (Bishop, 1999). The problem of precision may result in different conceptions on weight: students may conceive it as gravitational force or support (electromagnetic) force on the weighing scale (Galili & Kaplan, 1996). In addition, features such as the ontology (Chi, Slotta, & de Leeuw, 1994) and cause (Piaget, 1974) can be included in the conceptual definition. Moreover, operational definition of weight can be precise by including the following features: equipment (Robertson, 2008), direction

Table 2

Definitions related to Mixed Conception (definiendum and definiens)

Definitions related to Mixed Conception (definiendum and definiens)	
Definiendum (The term to be defined)	**Definiens** (The terms used in the definitions)
Heat: "the process by which energy transfers occur as a result of a temperature difference." (Carlton, 2000)	**Temperature**: Temperature is a measure of the concentration of heat energy. (Carlton, 2000)
Heat is energy which is transferred from an object at a higher temperature to another at a lower temperature, until they reach the state of thermal equilibrium. (Thomaz *et al*., 1995)	**Temperature** of a system is a property that determines whether or not a system is in thermal equilibrium with other systems. (Balamuth, Wolfe & Zemansky, 1941)
Energy is defined as the ability to do work. (Iona, 1973)	**Work** as an energy transfer between an agent and a recipient (Mungan, 2005) **Work** is the process of transferring energy to a system through the displacement of the system by an applied force. (Serway & Faughn, 2003)
Weight: Weight is the force of gravity acting on the mass and g is often called the acceleration due to gravity. (Johnson *et al*., 2000)	**Mass**: A common way of measuring an unknown mass is to use a balance to compare the weight of an unknown against the weight of a standard mass. (Beynon, 1994)
Charge (See *electric charged object*): Any object that can exert or feel the electric force. (Hobson, 2003)	**Electric Force** (See *electric force law*): Electrically charged objects exert forces on each other at a distance. (Hobson, 2003)
Electric Field: definition of electric field as electric force per unit charge. (Young & Freedman, 2004, p.806)	The **electric force** on a charged body is exerted by the electric field created by other charged bodies. (Young & Freedman, 2004, p.806)

(Iona, 1975) and reference frame (Iona, 1999).

Students may commonly conceptualize energy as a kind of substance (Warren, 1983). This can be attributed to the imprecise definition, "Energy is the ability to perform work", which does not specify the ontological status of energy. Hence, Arons (1999) explained using *The Feynman Lectures* that, "energy is not concrete; it is *not* a material substance." Alternatively, one may specify that energy is an abstract quantity. To be more precise, one could state that not all energies are able to perform work based on Second Law of Thermodynamics (Sexl, 1981).

Newton's Third Law of motion is sometimes simply stated as "Action equals reaction". This definition only suggests two features: there are two forces and they have the same magnitude. Note that Newton's Third Law may have three more features (See Table 3): act on different objects (object), in opposite directions (direction), and same kind of force (nature). Therefore, these features of definitions may help to develop a more precise conception of Newton's Third Law.

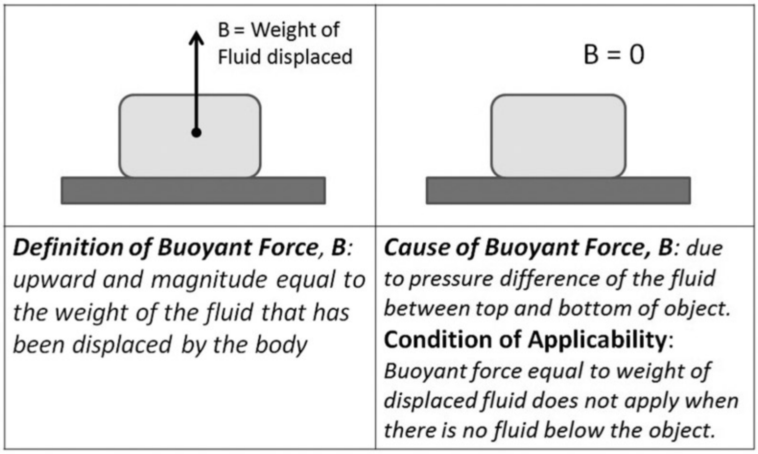
To be precise, the definition of heat may refer to the boundary of a system (Spalding & Cole, 1966). In general, the features of definitions could include nature or ontology, which is sometimes not stated in the definition of heat. The absence of these features, may also result in different conception of heat, such as sensation, substance, energy, process, or interaction, just to name a few examples.

As another example, the definition of buoyant force as discussed in the Introduction, also has the problem of precision due to omission of cause. Teachers could also include the *condition*

Table 3
Definitions related to Imprecise Conception I: (Lack of Features)

Definitions related to Imprecise Conception (Lack of Features)	
Less Precise Definitions	More Precise Definitions
Weight as a *result of weighing*. (Galili, 1993)	**Weight** implies a force exerted by something against support (or pivot) and equal to the contact, elastic, normal force exerted by the support (or pivot) on the object. (Galili, 1993)
Energy is the ability to perform work. (Iona, 1973)	**Energy** is *not* concrete; it is *not* a material substance; it is given meaning through the calculation of numbers. (Arons, 1999)
Newton's Third Law: Whenever one object exerts a force on a second object, the second object exerts an equal and opposite force on the first. (Hewitt, 2006, p.75)	Five Features of **Newton's Third Law** of Motion: 1. occur in pairs 2. are of the same kind (Electric or magnetic) 3. are of equal in magnitude 4. act along the same line, but in opposite directions 5. act on different objects. (Crundell, 2001)
Heat is energy that is being transferred from one system to another because of a difference in temperature. (Tipler, 2004)	**Heat** only has meaning when referred to the boundary of a system. It exists during the interaction only. (Spalding & Cole, 1966, p.92)

of applicability in this definition. For example, Archimedes principle is applicable for object which is partially floating, but it should exclude the situation when there is no fluid below the object. The inclusion of this feature may improve the precision of the definition of buoyant force. It affects how teachers and students determine whether the book placed on a table, is acted by a buoyant force (See Fig 3). Hence, the precision of definition provided may help to achieve a more precise conception of the physical concept. That is, the omission of this feature may result in a misconception or vague conception of a physical quantity when the definition in textbook is imprecise. We may name this kind of conception as 'Imprecise Conception'.



Definition of Buoyant Force, B: *upward and magnitude equal to the weight of the fluid that has been displaced by the body*

Cause of Buoyant Force, B: *due to pressure difference of the fluid between top and bottom of object.*
Condition of Applicability:
Buoyant force equal to weight of displaced fluid does not apply when there is no fluid below the object.

Fig. 3 *Definitions of Buoyant Force with/without cause and condition of applicability*

Another kind of imprecise conception can be attributed to the 'undefined features or definiens' in the definitions. These features being stated in some definitions should be further defined or explained. That is, the effect to students is as if the features are not present in their working memory when they are not sure of the definition of this term. Similarly, this feature may adopt a word which has multiple meanings, thereby misleading some students. To minimize this problem, we can avoid certain words with multiple meanings. For example, Newton's third law can be defined without the word, 'action', by stating that "To every force acting on a body there exists a corresponding force that is equal in magnitude but opposite in direction, exerted by the body (Crew, 1929, p.76)."

There are many words, such as ability, transfer, heat, disorder, or roundness, which are commonly not defined within the same text (See Table 4). There can be disagreement on how these words should be defined, and their meanings can differ for some scientists. For example, temperature could be defined in term of heat, but heat may be defined as substance (Newburgh, 2009), motion (de Berg, 2008) and interaction (Moore, 1993) or others. The conception of temperature may vary with students if their conception of heat is different. If students do not have working memory of these words and their definitions, or they remember another definition different from the intended meaning, this problem of definition may also result in 'imprecise conception' or alternative conception.

3. The Problems of Context

Many definitions may vary according to the technical usage, daily and historical context. For example, the definition of weight depends on the theoretical models adopted by geophysicists or metrologists. Although the mathematical definition of weight is commonly based on $W = mg$,

Table 4

Definitions related to Imprecise Conception II: (Undefined Features)

Definitions related to Imprecise Conception (Undefined or ill-defined Features)	
Imprecise Definition	Undefined or ill-defined Features
Energy is the ability to do work. (Iona, 1973)	The trouble is that ability is not defined, or depends on circumstances. (Swartz & Miner, 1996, p.160)
Heat: non-mechanical energy transfer. (Roche, 1971)	Transfer means complementary changes in the quantity of energy stored in interacting subsystems; it does not mean flow or any other form of transit. (Papadouris & Constantinou, 2010)
Temperature: Temperature is a measure of the concentration of heat energy. (Carlton, 2000)	Heat as a substance. (Newburgh, 2009) Heat is motion. (de Berg, 2008) Heat as an interaction. (Moore, 1993)
Entropy is a measure of the amount of disorder or in a system. (Giordano, 2010)	Unfortunately, the term disorder is deficient. First and foremost, there is no general definition of it in the context of thermodynamics. (Leff, 2007)
A planet is a celestial body that: 1. is in orbit around the Sun, 2. has sufficient mass to assume hydrostatic equilibrium (a nearly round shape), and 3. has "cleared the neighbourhood" around its orbit. (International Astronomical Union, 2006)	How are we to quantify the degree of roundness that distinguishes a planet? Does gravity dominate such a body if its shape deviates from a spheroid by 10 percent or by 1 percent? (Soter, 2007)

geophysicists may focus on g, the gravity measurement and metrologists are concerned on *m*, the traceability to a prototype kilogram (Van Camp *et al.*, 2003). Since weight can be defined in terms of mass and gravity, it is not a surprise when some students "equate weight with gravity" (Galili, 1993) or "confuse weight with mass" (Iona, 1975).

As for the problem of 'daily context', it was found that the word, force, can be used as a verb or noun in different languages (Itza-Ortiz *et al.*, 2003) or implied the meaning of energy (Grayson, 2004) and power (Gao, 1998; Suzuki, 2005). That is, force may refer to power or energy in daily life as defined in the dictionary, and its meaning is cultural dependent (See Fig 4). The influence of daily meaning to the technical meaning can also be found on the words, momentum and impulse, in Itza-Ortiz *et al.*' s (2003) study.

We may find the daily meanings of the technical words in the dictionary (Williams, 1999; Itza-Ortiz *et al.*, 2003; Suzuki, 2005), which students may have before lessons (Refer to Table 5 for a comparison of dictionary definitions or daily meaning with technical meaning of some physics terms). Note that the meanings of words in the dictionary are compiled by finding what various words have meant to some authors; it is not about providing authoritative statements on the 'true meaning' of words (Hayakawa & Hayakawa, 1990, p.34). Students may also learn the meanings of these words from the dictionary instead of physics textbooks.

In general, students may mix up the technical meaning of force, momentum, impulse, for example, with their meanings in everyday connotation (Williams, 1999; Itza-Ortiz *et al.*, 2003). This kind of conception can be coined as 'Mixed Conception' (Daily and Technical Context). In a sense, this is similar to intermediate conception that indicates a conception that has elements of both alternative (incorrect) conception and technical ('correct') conception (Grayson, 2004). That is, students may move back and forth between 'old' conception (daily meaning) and 'new' conception (technical meaning) depending on the context. However, if students can differentiate the daily and technical meaning of the words, they are likely to perform better in the assessments (Itza-Ortiz *et al.*, 2003).

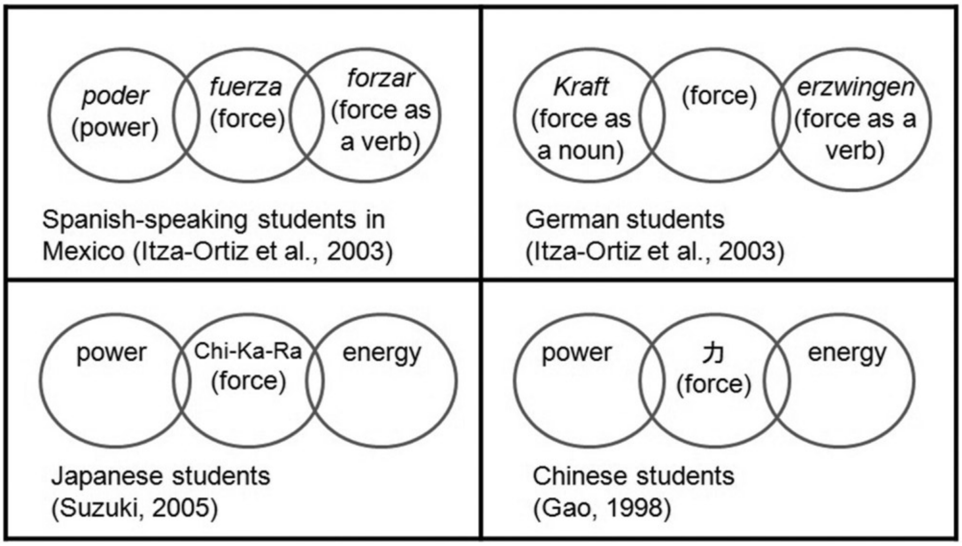


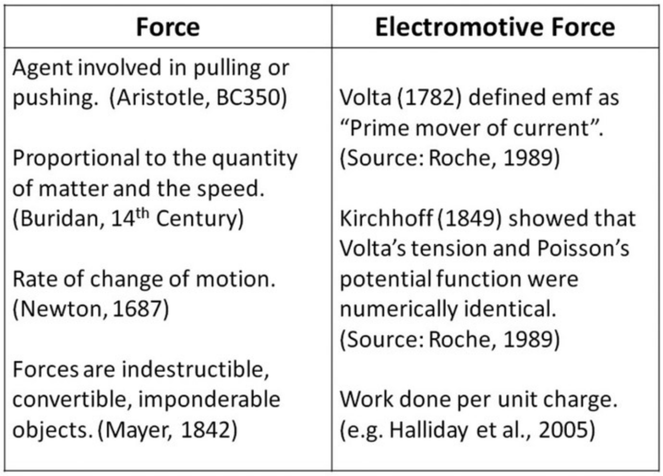
Fig. 4 *Cultural influence on the definitions of force*

Table 5

Definitions related to Mixed Conception: Daily and Technical Context

Definitions related to Mixed Conception (Daily and Technical Context)	
Dictionary Definitions / Daily Meaning	Technical Definitions
CHI-KA-RA (Force) has nine meanings involving 'physical strength', 'power', 'energy', 'ability', 'effort'. According to an English dictionary, the English word 'force' has 12 meanings, including 'violent action', 'physical strength', 'strong effect', 'power' … (Suzuki, 2005)	**Force**: We define the **force** F that an interaction exerts on a given object to be the *rate* at which momentum flows into the object because of that interaction. (Moore, 2003)
Velocity: Rapidity or celerity of motion; swiftness, speed. (Mendelson, 2003)	**Velocity**: Speed of an object and its direction of motion; a vector quantity. (Hewitt, 2006)
Impulse: One of the strong basic feelings that make people do things. (Itza-Ortiz *et al.*, 2003)	**Impulse**: the amount of momentum that a specific interaction contributes to a particle's momentum during a short time's interval. (Moore, 2003)
Energy: 1. dynamic quantity; 2. vigorous exertion of power; 3. the capacity for doing work; 4. power. (Williams, 1999)	**Energy**: the numerical sum of the kinetic energies of all particles in the system plus the potential energies of all their internal interactions. (Moore, 2003)
Weight: 1. the amount that a thing weighs; 2. relative heaviness. (Williams, 1999)	**Weight**: the gravitational force exerted on an object. (Moore, 2003)

Students may mix up the technical definitions of the words with not only their daily definitions, but their historical definitions. For example, the alternative conception, "motion implies force", can be attributed to Aristotle's concept in physics (Clement, 1982); motion was caused by 'inherent force' of object to seek its natural place. However, one may explain that this force was defined as *energy* (Grayson, 2004; Alvegard *et al.*, 2010). (Students can be considered correct if they believe in "motion implies energy".) On the contrary, 'electromotive force' that was defined as a force, it is now preferred to be defined as 'energy' (Fig 5). This term has been a



Force	Electromotive Force
Agent involved in pulling or pushing. (Aristotle, BC350) Proportional to the quantity of matter and the speed. (Buridan, 14th Century) Rate of change of motion. (Newton, 1687) Forces are indestructible, convertible, imponderable objects. (Mayer, 1842)	Volta (1782) defined emf as "Prime mover of current". (Source: Roche, 1989) Kirchhoff (1849) showed that Volta's tension and Poisson's potential function were numerically identical. (Source: Roche, 1989) Work done per unit charge. (e.g. Halliday et al., 2005)

Fig. 5 *The Evolution in the definitions of Force and Electromotive Force*

source of confusion to students for some time (Alexander, 1939).

The definition of heat has also evolved over time and it has been defined as motion (Bacon, 1620), substance (Black, 1775), and interaction (Hatsopoulos & Keenan, 1965), for example. It is common that students may mix up the technical definition with the historical definition (See Table 6). We may call this kind of conception as 'Mixed Conception' (Technical and Historical Context). Interestingly, students may even use mixture of concepts on force from three theories, namely Aristotelian, Impetus and Newtonian theories (Halloun & Hestenes, 1985). In other words, students may provide verbal or written representations of force, which are combinations of these three historical definitions.

There seems two different schools of thought on the alternative conception of force: Some explain that "motion implies force" is due to confusion of force with its daily definition (Itza-Ortiz *et al.*, 2003), and others explain with Aristotle's notion (historical definition) of force (Clement, 1982). Note that these two explanations on alternative conceptions are not contradictory but complementary; the daily (dictionary) definition of force, for example, can be influenced by their historical definition. Hence, some students are unable to distinguish the technical definition of force with its daily or historical definition. Simply put, students may mix up the technical definition of force with the definition of force in historical or daily context. Thus, it is difficult to pin-point the source of 'misconception', whether daily or historical.

4. The Problems of Completeness in knowledge

Students may think that they have complete knowledge of the physical concept after reading their textbooks; this is a misconception. Students may not be aware of the tentative nature of science, and some believe that laws and theories do not change. (Lederman & O'Malley, 1990). The fact is there are problems of completeness in knowledge even in the definition of weight. One criticism on the conceptual definition of weight is that the theoretical concept of gravitational force between the Earth and the object, is inaccessible to measurement

Table 6

Definitions related to Mixed Conception: Technical and Historical Context

Definitions related to Mixed Conception (Technical and Historical Context)	
Technical Definitions	Historical Definitions
Force: A **resultant force** is that *agent which changes the velocity (and momentum) of a body.* (Whelan & Hodgson, 1989)	Forces are indestructible, convertible and imponderable objects. (Mayer, 1842)
The **electromotive force** (e.m.f.) of a source is defined as the electrical energy produced per unit charge inside the source. (Breithaupt, 1995)	**Electromotive Force**: the force that separates positive from negative electricity, and avoids their reunion in the battery. (Gomez & Duran, 1998)
Heat: the energy in a substance as represented by molecular activities or configurations. (Stuart, 1938)	**Heat**: Thus heat is produced by motion. If it is matter, it must be admitted that the matter is created by motion. (Carnot, 1824, p. 68-69)
Mass is defined as Lorentz invariant, independent of velocity of the object. (Okun, 1989)	Transverse **mass** = $\mu\gamma$, Longitudinal **mass** = $\mu\gamma^3$ μ: mass of electron, γ: Lorentz factor **Mass** is velocity-dependent. (Einstein, 1905)
Displacement current: is not a flow of charge; nor is it a physical source of magnetic fields. (French, 2000)	**Displacement current**: a real flow of electricity across an insulating gap. (French, 2000)

(Iona, 1987); this ideal concept of weight does not really exist.

To be extremely precise, the weighing scale or spring scale does not always provide the correct 'weight', as the measured value is not linearly proportional to the mass of the body. The weighing scale does not have perfect linearity throughout a wide range of application, and it is possible to have errors during measurement. The effect of environment due to pressure, temperature and humidity may increase the errors of measurement too. Besides, every theoretical problem in physics is practically governed by nonlinear mathematical equation (Heisenberg, 1967). Hence, one may criticize the accuracy of operational definition of weight because of the problem of measurement in weighing scale.

While the theory of gravitation is continued to be researched, we may expect further redefinition on weight. Note that there are at least seven mysteries or unsolved problems on the nature of gravity (Brooks, 2009). The meaning of weight may change with new understanding on the nature of gravitational force. Hence, our knowledge on weight can be considered to be incomplete! Our incomplete knowledge on the physical concepts and their definitions can be coined as 'Incomplete Conception'. (See Table 7 for more examples.)

V. Implications and Limitations

This article suggests that the definitions that teachers adopt may contribute to the alternative conceptions of students. Hence, teachers should

Table 7

Definitions related to Incomplete Conception

Definitions related to Incomplete Conception	
Definitions	Problems of Incompleteness in Knowledge
Weight: The weight of an object refers to the net gravitation force exerted on it by all other objects. (Hobson, 2003) (All other objects may refer to dark matter, dark energy etc. in the universe.)	We know very little for sure about dark matter… We know even less about dark energy… (Wilczek, 2008, p.203)
Energy: The property of a system that enables it to do work. (Hewitt, 2006, p.125)	We have no knowledge of what energy is. (Feynman *et al.*, 1963)
Each force in a Newton's third law pair: • has the same magnitude (size) • acts along the same line but in opposite directions, • acts for the same time, • acts on a *different* object, • is of the same type (e.g. two contact forces, or two gravitational forces) • can be identified by changing round the words. (Johnson *et al.*, 2000)	The equality of action and reaction has almost no place in relativistic mechanics. It must essentially be a statement about the forces acting on two bodies, as a result of their mutual interaction at a given instant. And, because of the relativity of simultaneity, this phrase has no meaning. (French, 1968)
Mass: Mass as irreducible representations of the Poincaré group. (Wilczek, 2005)	We also don't really understand the masses of neutrinos… (Wilczek, 2008, p.202.)
Entropy: I have put forward 12 principles that have led me to conclude that Boltzmann's 1877 definition of the entropy in terms of the logarithm of the probability of macroscopic states of composite systems is superior to all other options. (Swendsen, 2011)	The issues I have discussed have been the subject of disagreements for well over a century. (Swendsen, 2011) "Nobody really knows what entropy really is." John von Neumann (Tribus & McIrvine, 1971)

develop pedagogy to help students in learning the definitions in physics. There seemed relatively *limited* physics education research studies on the pedagogy in definitions as compared to position papers on the correct definitions in physics. However, we may let students debate or discuss the preferred definitions (Carlton, 2000) with the help of these position papers. In addition, students should be aware of the problems in definitions, and this may help them to define physical concepts in future.

Students' ability to define a concept does not imply that they have fully understood the definition and its implication. For example, students may define acceleration in an acceptable manner, but they may not be able to apply the definition appropriately (Trowbridge & McDermott, 1981). Since memorization of the definition of a concept is relatively easier than understanding of its physical meaning; many students may prefer this way of learning for assessment. Hence, "learning of a concept" and "learning of a definition of a concept" are not necessarily the same thing (Smith & Ragan, 1999).

Teachers should be aware that textbook authors may adopt definitions which have varied precisions. Students should not be penalized unnecessarily if there is no consensus opinion on some definitions, such as heat. Note that a few textbooks may provide more precise definitions, with more features, than most of the textbooks. It is not definitely fair to assess students' knowledge on physical concepts by using venerable textbooks that adopt uncommon 'stricter' definitions. Hence, the definitions that we teach in classroom may have implications in learning and assessments.

We should be cognizant that the concepts in physics are closely related to their definitions. The experts' definitions of physical concepts do not necessarily or perfectly represent the concepts that they have in mind because of the challenges in defining physical concepts or the problems of definitions. Neither can all students comprehend the definitions fully because of their ability, attitude and the problems of interpretation. However, we observe that many definitions such as weight, energy, heat, can be defined alternatively and they can result in four variants of alternative conceptions. To summarize, definitions may lead to at least four kinds of alternative conceptions, such as 'operational conception', 'imprecise conception', 'mixed conception', and 'incomplete conception' (See Appendix A for an example). Thus, these problems of definitions could be discussed and included in future textbooks.

Last but not least, the validity of this meta-study is dependent on the criteria in selecting the research studies or journal papers. Essentially, it depends on the inclusion criteria whether the selected research studies have passed through peer review process, or they are merely expressed opinion in some works or websites. Better still, the selected research studies should have some discussions on the validity of their own research.

VI. Conclusions

It is important to emphasize that alternative conceptions are not mainly contributed by definitions available to students. This article suggests that the definitions that teachers adopt, may contribute to the 'alternative conceptions' in students. We suggest coining the phrase 'alternative definitions' to refer to the commonly available definitions of physical concepts adopted by physicists or textbook authors, which have problems of circularity, precision, context and completeness in knowledge. 'Alternative definitions', having the above definitional problems, may contribute to alternative conceptions. That is, the problems of definitions may lead to at least four main variants of alternative conceptions, such as 'operational conception', 'imprecise conception', 'mixed conception', and 'incomplete conception'.

In the contemporary world, students and teachers can access to more different definitions from internet or textbooks available all over the world. This may result in more alternative conceptions on the physical concepts. Besides, the classroom in this century may have more students from various parts of this globalized world. That is, students may come into the classroom with more varied background knowledge (a diversity of definitions pertaining to physical concepts).

To conclude, with the awareness on the problems of definitions, circularity, precision, context and completeness, it may help to facilitate definitions of physical concepts for deep understanding. Further development on

Appendix A: Alternative Conceptions on Weight

Table 8

Alternative Conceptions on Weight

Alternative Conceptions on Weight	
Alternative Definitions	Variants of Alternative Conceptions
Weight: *Weight is what bathroom* scales read. (Bishop, 1999) "the reading of a spring scale supporting the object, independent of any specification of how the spring scale is supported." (Iona, 1975) **Scales**: a piece of equipment used for weighing people or things. (Macmillan English Dictionary, 2007) **Spring Balance**: The device is often used to measure the weight of a body approximately. (Oxford Dictionary of Physics, 2005)	Operational conception
Weight: Weight is the force of gravity acting on the mass and g is often called the acceleration due to gravity. (Johnson *et al.*, 2000) Mass: A common way of measuring an unknown mass is to use a balance to compare the weight of an unknown against the weight of a standard mass. (Beynon, 1994)	Mixed Conception (definiendum and definiens)
Weight as a *result of weighing*. (Galili, 1993) **Weight**: …those who define ***weight*** as a *result of weighing*, which implies a force exerted by something against support (or pivot) and equal to the contact, elastic, normal force exerted by the support (or pivot) on the object. (Galili, 1993)	Imprecise Conception (Lack of Important Features)
Weight: 1. the amount that a thing weighs; 2. relative heaviness. (Williams, 1999) **Weight**: the gravitational force exerted on an object. (Moore, 2003)	Mixed Conception (Daily and Technical Context)
Weight: The weight of an object refers to the net gravitation force exerted on it by all other objects. (Hobson, 2003, p.99) (All other objects may refer to dark matter, dark energy etc. in the universe.) We know very little for sure about dark matter… We know even less about dark energy… (Wilczek, 2008, p.203)	Incomplete Conception

this proposed framework on 'Alternative Conception' can utilize the problems of definitions for improvement in textbook's presentation and classroom teaching. Note that these four challenges in definitions cannot be easily resolved. Educators and students should be cognizant of the variants of alternative conceptions, which can arise from alternative definitions. The concept of 'alternative definitions' can be useful and generalized in science education and possibly beyond. The importance of definitions should deserve more attention from educators and students.

It should be appropriate to end this paper with another insight from Feynman.

> *Test it this way: you say, "Without using the new word which you have just learned, try to rephrase what you have just learned in your own language." Without using the word "energy," tell me what you know now about the dog's motion. You cannot. So you learned nothing about science. That may be all right. You may not want to learn something about science right away. You have to learn definitions.*
>
> Feynman, 1969, p. 317

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