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Korean University Students' Understanding of Idealization in Mechanics and Its Implications for Physics Education

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ABSTRACT

This study investigated university students' (majoring physics education) understanding of some aspects of idealization frequently used in teaching and learning of physics, especially of mechanics. A total of 143 students were given a questionnaire of six questions requiring written responses. Out of the six questions, the first three were concerned with basic idealized concepts, the next two with the making of the assumptions of ideal conditions for given problem settings, and the last with the identification of the idealization used in the given solution of a problem. Students' written responses were grouped into patterns and the relative frequencies of the patterns were counted. It was found that the students had limited understanding of the idealization and their ideas were diverse and frequently incorrect. The implications of the findings are discussed in relation to the roles of idealization in physics education.

Key words: Korea, university student, idealization, mechanics, assumption

I. Introduction

For the last two decades, numerous studies have shown that students of all school levels have only limited understandings of basic concepts of science and that science teaching at schools is insufficient in changing their understanding (e.g. Driver *et al.*, 1985; Osborne & Freyberg, 1985; Nersessian, 1989). For instance, even college students majoring in science tend to think that an object moving on a smooth surface would stop unless a force is applied to it to maintain its motion and would move at a uniform speed if a constant force

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acted on it (e.g. Viennot, 1979; Park *et al.*, 1991). These students seem not to understand the most fundamental concepts of force and motion (i.e. Newton's laws of motion), which are surely the starting points of any advanced learning of mechanics or physics as a whole.

Why do students fail to show a reasonable level of physics learning? One of the reasons for this seems to be the fact that they do not have proper understandings of some idealization used in the given situations of physics. In other words, when students learn, or are asked to apply the basic concepts of physics, they do not pay, or are not asked to pay, attention to the assumptions and conditions which were used in the process of formulating the concepts (Song *et al.*, 1997). Thus they do not appreciate the nature and the limits of the concepts in relations to the corresponding phenomena.

Generally in science, particularly in physics, various kinds of idealization are frequently used as essential elements of the discipline and thus play important roles in its teaching and learning. For example, in physics, most of its knowledge system is based on some basic idealized concepts (such as, mass point, rigid body, ideal gas, simple harmonic motion, blackbody radiation), textbooks are full of example problems, solutions of which require various assumptions of idealization (such as, the earth is a perfect sphere, the amplitude of oscillation is small enough, the internal resistances of batteries are negligible, the gas is an ideal gas). The interpretation of practical work also requires careful consideration of the effects of hidden factors (such as, the mass of a string, the friction of a track, the rolling of a ball, the temperature variation of resistance).

As mentioned earlier, despite a vast number of researches which have investigated students' misconceptions (or alternative frameworks) in various areas of the discipline (e.g. Pfundt & Duit, 1988; Driver *et al.*, 1994) and explored the effective ways of changing students' existing conceptions (e.g. Cosgrove & Osborne, 1985; Champagne *et al.*, 1985; White & Gunstone, 1994; Glynn, 1991; Stinner 1994), there have been few studies of how students understand the issue of idealization in physics in particular or in science in general. Only a few science educators have recently begun to recognize the importance of idealization in science education. For example, Arons (1990) argued that the decision whether or not a certain factor could be negligible has a crucial effect on the success of problem solving. Matthews (1994) gave the explanation of Galileo's idealization in dealing with the motion of the pendulum.

With this background, this study was designed to investigate university students' understanding of some aspects of idealization frequently used in mechanics and to explore the implications of the results in the teaching and learning activities of physics.

The research problems of this study are as follows:

- How do students understand some basic idealized concepts?
  (i.e. ideas of idealized concepts)

- What kind of assumptions do students make about ideal conditions to solve given problems?
  (i.e. assumptions of ideal conditions)
- How do students identify idealization within a given set of problem and its solution?
  (i.e. identification of idealization)

Ⅱ. Method and procedure

A total number of 143 students were sampled in the study. The subjects were the students who took some major courses (e.g. introductory physics, mechanics, modern physics) of the first three years of the physics teacher pre-service training programme (in Korea, the programme is four years long, like most other programmes in Korean universities) of two national universities and one private university which are considered to be only slightly different from one another and to be near to the national average in terms of their academic standards.

The questionnaire contained six questions demanding written responses (see Appendix). Out of the six questions, the first three were concerned with the students' ideas of some basic idealized concepts (i.e. Free Fall, Mass Point, and Perfectly Elastic Collision), in which they were asked to express their understandings of the concepts. The next two questions were on making assumptions about ideal conditions, in which the students were asked to show what kinds of idealized conditions they thought would be necessary to solve particular problems (i.e. Pulling a Box and Basketball) effectively. The last was concerned with the identification of idealization. The question presented a problem with its typical solution (i.e. Velocity of Falling) and asked students to identify the kinds of idealization which had been used in the solution of the problem.

Qualitative data from the questionnaire were analyzed so that relative frequencies (i.e. percentages) could be counted according to the patterns in the responses. However, no attempt was made to compare the performances of different grade levels and of different sexes, because the sizes of the samples for each grade level and for each sex were not evenly distributed and were not big enough in order to have any strict statistical comparison and because each year's coverage of the required knowledge for answering the question were slightly different from university to university. Instead, most attention was given to identifying the patterns in the responses and grouping them.

Ⅲ. Data and results

1. Ideas of idealized concepts

In these three questions, extracts of typical sentences which contain the terms of three basic idealized concepts (i.e. Free Fall, Mass Point and Perfect Elastic Collision) were given, and students were asked to give their own ideas about the concepts. Students' responses were classified into patterns each of which represents a coherent idea and the patterns were analyzed in terms of their relative frequencies and the relationships amongst them.

(1) Free fall

Table 1 shows the result of the analysis of the students' responses to Question 1. Nearly a third of the students (30.8%) considered 'free fall' as 'falling maintained only by gravitation'. Another a third showed three different ideas - that is, 12.6% as 'falling without air resistance', 10.5% as 'falling maintained only by gravitation and without air resistance', and 9.1% as 'natural falling with no external force'.

Table 1. Students' ideas of 'Free fall'. (n=143)

Patterns of ideas		%
FREE FALL is the falling ...		
Only one idea expressed	(1.1) *maintained only by gravitation*	30.8
	(1.2) *without air resistance*	12.6
	(1.3) *with zero initial velocity*	4.2
	(1.4) *vertically*	1.4
Two ideas expressed	(1.5) *without air resistance & only by gravitation*	10.5
	(1.6) *with zero initial velocity & only by gravitation*	5.6
	(1.7) *vertically & only by gravitation*	1.4
	(1.8) *with zero initial velocity & without air resistance*	2.1
	(1.9) *vertically & without air resistance*	2.1
	(1.10) *vertically & with zero initial velocity*	2.1
Three ideas expressed	(1.11) *with zero initial velocity & without air resistance & only by gravitation*	0.7
	(1.12) *vertically & without air resistance & only by gravitation*	2.1
	(1.13) *vertically & with zero initial velocity & without air resistance*	0.7
Different idea expressed	(1.14) *naturally without any external force*	9.1
	(1.15) *at constant acceleration*	0.7
	(1.16) *in a weightless situation*	2.1
	(1.17) *maintained by gravitation & by air resistance*	2.1
	Others	6.3
	No response	1.4
Total		100.0

The implication from the data is that students tend to regard 'free fall' as some combinations of the following four basic ideas: 'falling maintained only by gravitation', 'falling without air resistance', 'falling with zero initial velocity', and 'vertical falling'. To explore such combinations the following codes were used: 1.5=1.1+1.2; 1.6=1.1+1.3; 1.7=1.1+1.4; 1.8=1.2+1.3; 1.9=1.2+1.4; 1.10=1.3+1.4; 1.11=1.1+1.2+1.3; 1.12=1.1+1.2+1.4; 1.13=1.2+1.3+1.4.

Most students appeared to possess various forms of the ideas of 'free fall', which differ only partly in their sub-elements from the following synthesis of conceptions of the students, 'free fall is the motion of vertical fall, maintained only by gravitation but with zero initial velocity and no air resistance'. In physics, free fall is defined as "the accelerated motion towards the center of the Earth of the body acted on by the Earth's gravitational attraction and by no other force" (Parker, 1983). Apart from the responses of 1.1 and of 1.5, therefore, these ideas are somewhat different from the accepted concept.

In most physics textbooks of secondary schools and universities' introductory courses, 'vertical falling motion by gravitation but with zero initial velocity and no air resistance' is frequently given as the ideal example of free fall, whereas 'vertically upward motion' and 'projectile motion' are often treated as different kinds of motion. But 'vertically upward motion' and 'projectile motion' are not different from 'free fall' because they differ from the latter only in terms of the initial conditions (i.e. velocity and direction) which are not crucial elements of the definition of the concept. Thus, the reponses including the ideas of 'with zero initial velocity' or of 'vertical fall' - that is, those of 1.3, 1.4, 1.6, 1.7, 1.8, 1.9. 1.10, 1.11, 1.12 and 1.13 - seem to reflect this kind of misunderstanding.

(2) Mass point

Table 2 shows the result of the analysis of the students' responses to Question 2. On 'mass point', more than twenty percent (21.0%) of the students considered it as 'the center of mass' coded as 2.1, while 7.0% considered it as 'center of the body' coded as 2.3 and 5.6% as 'action point of external force (s)' coded as 2.9.

The responses which had partial correspondence with the scientific meaning of mass point - i.e. 'point (s) considered to be the concentration of a certain amount of mass' - were the responses of 2.4, 2.5 and 2.10, which together summed to 24.5% of the total students.

There was a strong tendency for students to consider 'mass point' as the center of mass (i.e. 2.1, 21.0%), or of weight (i.e. 2.2, 12.6%), or of the body (i.e. 2.3, 7.0%), or as some point (s) related with these three concepts - that is, mass, weight and body - (i.e. 2.6 to 2.9, altogether 11.9%). In particular, responses 2.2 and 2.8 showed that the students were even confused the concept of 'mass' with that of 'weight'.

If students possess these kinds of incorrect conceptions of 'mass point', they would have a considerable difficulty in grasping the accurate meaning of more advanced related concepts, such as, 'law of universal gravitation', 'system of particles', and 'solid body'.

Table 2. Students' ideas of 'Mass point'. (n=143)

Patterns of ideas			%
MASS POINT is ...			
Center of something	(2.1)	*the center of mass*	21.0
	(2.2)	*the center of weight*	12.6
	(2.3)	*the center of the body*	7.0
Particular point (s) of something	(2.4)	*point (s) with mass but without size*	9.8
	(2.5)	*point (s) of concentrated mass*	12.6
	(2.6)	*point (s) of concentrated weight*	1.4
Individual point of something	(2.7)	*each point with mass*	4.2
	(2.8)	*each point with weight*	0.7
Action point (s) of force (s)	(2.9)	*action point (s) of external force (s)*	5.6
	(2.10)	*action point (s) of internal force (s)*	2.1
		Others	5.6
		Irrelevant responses	10.5
		No response	7.0
		Total	100.0

(3) Perfectly elastic collision

Physics textbooks generally use both of the terms, 'elastic collision' and 'perfectly elastic collision', equivalently. For this reason, the term 'perfect elastic collision' was intentionally used here in order to make a clear contrast with 'inelastic collision'.

As shown in table 3, on 'perfectly elastic collision', 7.6% of the students considered it as 'collision where momentum is conserved' (i.e. 3.3), while 6.4% considered it as 'collision that velocity (or speed) is transferred' (i.e. 3.7), 4.5% as 'collision that kinetic energy is transferred' (i.e. 3.8) and another 3.2% as 'collision that the force is transferred' (i.e. 3.9). That is, these students considered it as the collision in which something is conserved or transferred. On the other hand, a number (8.9%) of the students considered it as 'collision that there is no (or no loss of energy by) friction' (i.e. 3.16) and a few students (3.2%) as 'head-on collision' (i.e. 3.17).

A total of 33.7% of the responses (i.e. 3.1 + 3.2 + 3.18) showed some scientific ideas of 'perfectly elastic collision' as 'collision that (kinetic) energy is conserved'.

In many cases of the responses (i.e. 3.5, 3.7, 3.8, 3.10 and 3.12), students incorrectly regarded the specific cases of the collision in which two bodies happen to have the same masses (i.e. $m1 = m2$) as the general case of collisions. In addition, a small proportion (1.3%), coded as 3.19, of students said that 'perfect elastic collision' is the collision 'that elasticity = 1', due to the confusion caused by their similar names.

Table 3. Students' ideas of 'Perfectly elastic collision'. (n=143)

Patterns of ideas		%
PERFECTLY ELASTIC COLLISSION is the collision where ...		
Something is conserved	(3.1) *energy (kinetic, mechanical etc.) is conserved*	19.1
	(3.2) *kinetic energy & momentum are conserved*	14.0
	(3.3) *momentum is conserved*	7.6
	(3.4) *force is conserved*	1.9
	(3.5) *velocity (or speed) is conserved*	1.9
	(3.6) *object's states (e.g., size, shape etc.) are conserved*	1.3
Something is transferred	(3.7) *velocity (or speed) is transferred*	6.4
	(3.8) *kinetic energy is transferred*	4.5
	(3.9) *force is transferred*	3.2
	(3.10) *motion is transferred*	0.6
After collision something would happen	(3.11) *(after collision) bodies move to the opposit directions*	4.5
	(3.12) *(after collision) bodies scatter with an angle of 90°*	2.5
	(3.13) *(after collision) bodies scatter with the same angle*	1.9
	(3.14) *(after collision) bodies move to the same direction*	1.9
	(3.15) *(after collision) bodies scatter with the same speed*	1.9
Different idea expressed	(3.16) *there is no friction (or no loss of energy by friction)*	8.9
	(3.17) *the collision is head-on*	3.2
	(3.18) *coefficient of restitution = 1*	0.6
	(3.19) *elasticity = 1*	1.3
	Others	6.4
	Irrelevant responses	2.5
	No response	3.8
	Total	100.0

Compared with the first two questions, this produced more diverse patterns of responses, which suggests that students' ideas of 'perfectly elastic collision' are very complicated and less accurate. As shown here, if students' understandings of 'perfectly elastic collision' are so diverse and different from the scientific one, it is hard to imagine how they would successfully learn thermodynamics, fluid dynamics, and modern physics which are heavily based on this concept.

2. Assumption of idealized conditions

It is always the case that physics problems do not contain all the information of the conditions which are necessary to define the problem clearly and to make it physically meaningful. The rest of the job, thus, is left for learners to handle for themselves. Consequently, it is vital for students to make necessary assumptions of idealization for a given problem setting in order to make it more manageable.

As frequently experienced in ordinary physics learning, in each of the two questions (i.e. Question 3 & 4), students were given a typical setting of a problem and asked to articulate their assumptions which could be used to solve the problem effectively. The students' responses here were analyzed in terms of the following broad groups of their patterns:

- relevant or proper conditions
- unnecessary or incorrect conditions
- repeat of the instruction (of the problem)
- explaining the problem situation
- tactics of problem solving
- attempting to solve the problem by using equations

(1) Pulling a box

The most typical assumptions, as would be expected, were on friction between the floor and the box. More than three quarters of the students mentioned some sorts of conditions of friction - either 'there is no friction or no effect of it (e.g. no loss of energy by friction)' (54.6%), or 'whether there is no friction or a constant friction should be decided' (14.7%), or 'there is a constant friction' (8.4%). 13.2% of the students noticed the importance of gravitational effects (i.e. 4.4). Comments like "The floor is horizontal" (i.e. 4.8) could also be classified into this group. The next most popular assumption was 'there is no air resistance' (i.e. 4.5, 8.4%) (see Table 4).

Very few students acknowledged the relevance of other factors. For example, less than 4% of the students made assumptions either that 'the box is a mass point' (i.e. 4.6) or that 'F acts at the center of mass of the box' (i.e., 4.9), and only 2.1% assumed that 'the string has no mass' (i.e. 4.7).

Many students just repeated the information which was already provided in the given instruction of the problem. These are coded like 4.13, 4.14 and 4.15. These students might have imagined the actual situation, in which somebody attempts to pull a box, and responded accordingly.

Some also mentioned physically unnecessary or incorrect conditions which illustrate their misconceptions or insufficient understandings. For instance, despite the fact that the vertical components of F, gravitational force and normal force are cancelled out, a few students made assumptions of 'there is no other force, other than F' (i.e. 4.10), or 'there is no gravitation' (i.e. 4.11). In addition, some showed incorrect understandings of basic physics even by comparing entities which have different dimensions (i.e. force and mass, in 4.12).

Table 4. Assumptions of idealized conditions for solving 'Pulling a box'. (n=143)

		Patterns of students' assumptions	%*
Relevant or proper conditions	(4.1)	*there is no (effect of) friction*	54.6
	(4.2)	*there is either no friction or a constant friction*	14.7
	(4.3)	*there is a constant friction*	8.4
	(4.4)	*(the acceleration of) gravitation is constant*	13.2
	(4.5)	*there is no air resistance*	8.4
	(4.6)	*the box is a mass point*	2.8
	(4.7)	*the string has no mass*	2.1
	(4.8)	*the floor is horizontal*	2.1
	(4.9)	F *acts at the center of mass of the box*	0.7
Unnecessary or incorrect conditions	(4.10)	*there is no force, other than* F	2.8
	(4.11)	*there is no gravitation*	1.4
	(4.12)	F should be bigger than m.	1.4
Repeat of the instruction	(4.13)	*the force* (F) *remains constant*	13.9
	(4.14)	*the angle* (θ) *remains constant*	7.0
	(4.15)	*the mass* (m) *remains constant*	2.1
Explaining the problem situation	(4.16)	F *is bigger than friction after the start of moving*	1.4
	(4.17)	*because of Newton's 3rd law,* F = *friction*	2.8
	(4.18)	*force and acceleration are vector entities*	2.1
Tactics of problem solving	(4.19)	*a simple/clear diagram would help to solve the problem*	1.4
	(4.20)	*we have to decide the unit system (mks or cgs) first*	0.7
Attempting to solve the problem by using equations	(4.21)	just solving the problem by using known equations (e.g., $Ma = F\cos\theta$. $a = F\cos\theta/M$ or $F = Ma$, $a = F/M$)	32.9
		No response	2.1

* This percentage represents the proportion of the students whose responses belong to each response pattern out of the total students.

Nearly a third of the students did attempt to solve the problem by using some equations (i.e. 4.21). They did not follow the instruction of the question. Perhaps this was because what was required in the question is never experienced in ordinary physics lessons. Although they also failed to meet the requirement of the instruction, the students who gave responses coded as 4.19 and 4.20 suggested some useful general ways of solving physics problems.

Table 5. Assumptions of idealized conditions for solving 'Basketball'. (n=143)

		Patterns of students' assumptions	%*
Relevant or proper conditions	(5.1)	*there is no (effect of) air resistance*	43.4
	(5.2)	*there is no (effect of) wind*	6.3
	(5.3)	*there is (effect of) rotation of ball*	2.8
	(5.4)	*the ball is a mass point*	2.8
	(5.5)	*the ring is big, strong, firm enough for the play*	2.1
	(5.6)	*the ball is thrown exactly to the ring*	2.1
	(5.7)	*the floor and the ring are horizontal*	1.4
	(5.8)	*the ball is thrown higher than* h_2	1.4
	(5.9)	*the radius of the ball is known*	1.4
Unnecessary or incorrect conditions	(5.10)	*(acceleration of) gravitation remains constant*	16.1
	(5.11)	*the difference of the heights,* $\Delta h=h_2-h_1$, *is known*	5.6
	(5.12)	*player's action (force and gravitation) acts on the ball*	2.1
	(5.13)	*the mass of the ball is known*	1.4
	(5.14)	*there is no mass of the ball*	0.7
	(5.15)	*no force is given from the player*	0.7
Repeat of the instruction	(5.16)	*the angle (* θ *) remains constant*	9.1
	(5.17)	*the throwing force remains constant*	2.8
	(5.18)	*the height (h) of throwing remains constant*	1.4
Explaining the problem situation	(5.19)	*the ball will have a parabolic motion*	22.3
	(5.20)	*the motion will be of a constant acceleration*	3.5
	(5.21)	*there will be constant horizontal* v *and vertical* a	3.5
	(5.22)	*the total energy will be conserved*	2.1
Tactics of problem solving	(5.23)	*calculate* v_x *and* v_y *first, then consider* $v_y=0$ *at the top*	1.4
	(5.24)	*calculate* v *after separating x & y components of force*	0.7
Attempting to solve the problem by using equation	(5.25)	just solving the question by using equations (e.g., $U_1 + K_1 = U_1' + K_1'$ or $v_x = v_0 \cos\theta$ and $v_y = v_o \sin\theta - 1/2\ gt$ or $s = v_0 t + 1/2\ at^2$)	9.8
		No response	19.6

* This percentage represents the proportion of the students whose responses belong to each response pattern out of the total students.

(2) Basketball

Nearly a half of the responses mentioned the assumptions related to the conditions of the air, that is, 43.4% of that mentioned 'there is no (effect of) air resistance' and another 6.3% of that mentioned 'there is no (effect of) wind'. Only a few students, however, acknowledged the relevance some other factors, for example, the possibility of the rotation of the ball (i.e. 5.3) and the concept of mass point (i.e. 5.4). Smaller number of the students also mentioned the conditions of some other, less crucial, factors, as coded in 5.5 to 5.9 (see table 5).

About 16% of the responses commented on an unnecessary condition of a constant gravitation. That is, in this setting of problem, it is certainly not realistic to imagine that the gravitation (or its acceleration) would be different at any place in the basketball court - for example, the height of Mt. Everest would make less than 1% difference in the gravitation.

The responses of 5.11 to 5.15 show that students sometimes either pay attention to unnecessary entities which are not needed to answer my question (i.e. the difference of the heights in 5.11 and the mass of the ball in 5.13) or illustrate their misunderstandings (i.e. no mass of the ball in 5.14 and no force given to the ball in 5.15).

As in the previous question, a little of the responses (13.3%) mentioned the information which had been already given in the instruction (i.e. 5.16 to 5.18).

Unlike the previous question, only 9.8% of the students attempted to solve the problem by using some equations. In this case, a lot more students gave rather simple explanations which describe or predict the motion, in particular, more than twenty percent of the students described the fact that the ball would have a parabolic motion (i.e. 5.19). In addition, the rate of no response was also higher (i.e. 19.6%). These differences from the responses to the previous question might be caused by the fact that this problem is of less typical style. Some students mentioned general ways of solving physics problems, like coded as 5.23 and 5.24.

3. Identification of idealization (Velocity of falling)

Here, students were given a problem (of calculating the velocity of a falling body when it hits the ground) with its solution and asked to find, by examining the provided solution carefully, what kinds of idealization were used in the process of solving the problem. The students' responses were grouped and analyzed in terms of the criteria used for the last two questions where similar responses were required.

Table 6 shows the result of the analysis of students' responses to Question 6. The most popular responses were concerned with 'free fall', especially with 'air resistance'. As with the first question described in this paper, these responses also included various forms of idea of the concept (i.e. from 6.1 to 6.5 and 6.10). Other factors identified by the students were as follows: energy conservation (i.e. 6.6), mass point (i.e. 6.7), the direction of gravitation (i.e. 6.8), the buoyant force of the air (i.e. 6.9), the rotation of the body (i.e. 6.11), and the density of the air (i.e. 6.12).

Table 6. Identification of idealization in the solution of 'Velocity of falling'. (n=143)

		Patterns of students' identification	%*
Relevant or proper identification	(6.1)	*there was no (effect of) air resistance*	32.0
	(6.2)	*the motion was a free fall*	28.4
	(6.3)	*(acceleration of) gravitation remained constant*	26.6
	(6.4)	*gravitation was the only force acting on the body*	13.0
	(6.5)	*there was no initial speed/velocity*	11.8
	(6.6)	*the total (mechanical) energy was conserved*	5.3
	(6.7)	*the body was a mass point*	3.6
	(6.8)	*gravitation was downward, to the center of the Earth*	1.8
	(6.9)	*there was no buoyant force by the air*	1.8
	(6.10)	*the falling was vertically downward due to gravitation*	1.2
	(6.11)	*there was no rotation of the body*	0.6
	(6.12)	*the density of the air was constant*	0.6
Unnecessary or incorrect identification	(6.13)	*this happened in weightless space (so, no air resistance)*	14.2
	(6.14)	*the mass of the body is negligible*	3.0
	(6.15)	*the body was a rigid body*	1.8
	(6.16)	*the collision between the body and the ground is elastic*	0.6
Explaining the problem situation	(6.17)	*the falling is an (uniform) acceleration motion*	11.8
	(6.18)	*the motion is downwards due to gravitation*	1.8
	(6.19)	*the distance is proportional to the square of falling time*	1.2
	(6.20)	*the speed of falling is not affected by body's mass*	0.6
	(6.21)	*the energy is related only to the height*	0.6
	(6.22)	*gravitational mass = inertial mass*	0.6
	(6.23)	*the velocity will be maximum at the ground*	0.6
Attempting to solve the problem by using equations	(6.24)	just solving the question by using equations (e.g., $h = v_0t + 1/2\,gt^2$ or $E_k + E_p$ = constant or $v = \sqrt{2gh}$)	17.8
		No response	5.9

* This percentage represents the proportion of the students whose responses belong to each response pattern out of the total students.

Responses coded as 6.13 clearly show a typical misconception of the relation between gravity and air - that is, 'no air causes weightlessness' (e.g. Ruggiero *et al.* 1985). In addition, responses coded as 6.14 to 6.16 illustrate students' attention to rather irrelevant factors. There were also a number of responses which just explained or predicted the motion of the body, especially those coded under 6.17, and which tried to solve the problem using some equations coded as 6.24 rather than pointing out the used idealization. On the other hand, unlike the previous two questions, there was no responses related to general tactics of problem solving, perhaps because the solution of the problem itself was given in the question.

4. Summary of the findings

This study investigated university students' understandings of idealization in the following three areas: students' ideas of idealized concepts (Free Fall, Mass Point, and Perfectly Elastic Collision), making assumptions of the ideal conditions for given problem settings (Pulling a Box and Basketball), and identification of the idealized conditions used in the solution of a problem (Velocity of Falling).

For the ideas of idealized concepts, students showed low portions of correct ideas, below a half (that is, 41.3% for Free Fall, 24.5% for Mass Point and 33.8% for Perfectly Elastic Collision). Students tended to consider Free Fall as various combinations of four basic ideas (that is, 'maintained only by gravitation', 'without air resistance', 'with no initial velocity', and 'vertical falling'). For Mass Point, there was a tendency for them to consider it as the center/point (s) of different physical entities - that is, mass, weight, body and forces (for example, 'the center of mass', 'the center of weight', 'points of concentrated mass', and 'action point of external force'). In the case of Perfectly Elastic Collision, students tended to regard it as the collisions where some entities are either conserved or transferred (for example, 'that energy is conserved', 'that momentum is conserved', 'that velocity is transferred', and 'that energy is transferred').

For the making assumptions of idealized conditions, many students were able to pick up a few factors, such as, 'there is no or constant (effect of) friction' for Pulling a Box and 'there is no (effect of) air resistance' for Basketball. However, only a small portion of them were able to make assumptions of less apparent and more subtle factors, such as, 'box as a mass point' and 'massless string' for Pulling a Box, and 'no rotation of ball' and 'ball as a mass point' for Basketball. Many of them also did not follow the instructions of the questions as required. Instead, they just repeated the information in the instructions, or explained or predicted the motion of the body, or directly attempted to solve the problem by using equations. Some of them also hinted at their insufficient understanding or misconceptions by giving unnecessary or incorrect conditions. And similar tendencies were repeated in the identification of idealization (Velocity of Falling), with a particularly high rate of misconception of the relation between weightlessness and no air.

In short, it is shown from this study that the students have limited understanding of the idealization used in physics and also their ideas and understandings are quite diverse and frequently incorrect.

IV. Discussion

Since in physics idealization is crucial for the understanding of basic concepts and applications, without a proper understanding of idealizations there are considerable difficulties in grasping accurate meanings of more advanced concepts. Students' learning is greatly influenced by the kinds of ideas they have about these concepts and by how they perceive and characterize physical phenomena in relation to idealization.

For example, in the case of motion of an object on a smooth surface mentioned earlier, some idealization (such as, 'surface without friction', 'space without air resistance', 'surface with the same potential energy') are assumed. Students will therefore only appreciate the difference between their everyday experience of the phenomena (in which the object slows down due to friction) and the ideal setting of the physical event (in which its motion obeys Newton's 2nd law), if they are equipped with necessary understanding about the idealization.

Similarly, in the process of deriving the equation of motion of a simple pendulum, many assumptions (like, 'a string without mass', 'a string with the same length', 'space without air resistance', 'bob as a mass point', 'small enough amplitude of oscillation' and so on) are used. Consequently, students will only understand properly the application and limits of the equation of motion, if they understand all the ideal conditions. Furthermore, only if they understood these idealizations, the students will be able to obtain correct understandings of more complex and realistic physical phenomena - such as Borda pendulum, Kater pendulum, the motion of the pendulum of clock, and the motion of a swing in playgrounds - and to understand why they have to study the problem of a simple pendulum over and over again with some more complexity whenever they are introduced by one more de-idealizing factor of the motion - that is, 'the bob can not be considered as a mass point', 'the air resistance is not negligible', 'the amplitude of the oscillation is not small enough to be neglected' and so on.

Natural phenomena around us are affected by so many factors that it is almost impossible for us to understand them directly without some sorts of simplification. Thus, when we study and teach physics, we first make the phenomena as simple as possible and solve them with simple mathematical techniques, then, based on these simplified versions of the problems and solutions, we gradually consider other relevant factors one by one so that the formulation of the problem and the solution provide more accurate predictions. In fact, the contents of physics of different levels of schooling are arranged in this order and most textbooks, which would be the very way of transmitting existing knowledge claims (i.e. paradigms) to the next generation (Kuhn, 1962), are also written in this manner.

It is, therefore, essential for us to encourage students to develop more accurate understandings towards what kinds of idealization and mathematical techniques are used and towards what would be the limits of them. Otherwise, students can not properly understand the general structure of the discipline and appreciate the limits of the knowledge system of each level of physics learning.

From the pedagogical point of view, idealization helps to make complex natural phenomena, through its simplification and abstraction, into simple physical events which are more intellectually accessible, and allows students to concentrate their thinking into more physically important factors. At the same time, through its simplification and abstraction again, idealization widens the gap between the real natural phenomena and the physical events and encourages students to possess separate knowledge systems, scientific and everyday, (e.g. Solomon, 1983; Song, 1990) and eventually would somehow hinder the application and the transfer of scientific knowledge to their everyday situations.

There have been a substantial number of studies which investigated the effects of task contexts on students' performance of science (e.g. Rief & Larkin, 1991; Song & Black, 1991, 1992; Millar & Kragh, 1994; Gomez *et al.*, 1995; Choi & Song, 1996). Basically, those studies have illustrated the necessity for changing the present situation, in which school science education is formalized and separated from students' everyday experience, and explored possible solutions for it.

However, those studies should not be interpreted to suggest that abstraction and idealization which are the essential feature of present school science are meaningless or something to be removed.

On the contrary, they rather imply that typical tasks of science with lots of idealization need to be presented alongside more concrete and realistic examples of everyday life contexts in order to achieve better understandings of the relationships between them. In this respect, it is a rather unsatisfactory situation that school textbooks are full of highly abstracted and idealized examples while students want to learn the concepts with various concrete examples around their own everyday lives and that there is little attempt to bridge the gap between the two different worlds (Song & Choi, 1994).

What are the implications of this study? One of the lessons which we could learn from this study is that when we teach physics we need to stress the importance of idealization especially when a new more advanced concept is revised from its previous simpler forms. Students need to be encouraged to discuss actively the hidden factors and assumptions, which are usually treated without special attention, and to communicate their ideas so that they can appreciate the complexity and importance of the idealization.

We hope that, through this study, the importance of idealization had been raised and other research will follow similar lines. For example, we would like to carry out similar studies in other areas of physics (e.g. electromagnetism, thermodynamics, optics, modern physics), or in other fields of science (esp. chemistry), or in some other areas of science education (e.g. the roles of idealization in perceiving and mentally representing physical phenomena, or in designing experiments and interpreting data, or in communicating scientific ideas).

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[Appendix] The Contents of the Questionnaire

(1-3) The following extracts are some examples of the sentences which you can find in ordinary physics textbooks. The term, underlined in each extract, contains some specific assumptions or conditions of idealization. **What is the physical meaning of each underlined term?**

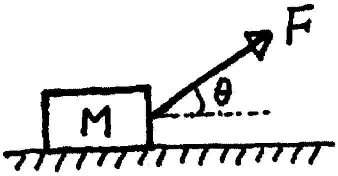
(1) "... a free falling body has an acceleration of g. That is, it moves at a uniform acceleration. Thus, the velocity of the body would be $v=gt$, and the distance which the body fell would be $y=1/2gt^2$ ...."

(2) "... Newton thought that each mass point would contribute to the gravitational attraction which the earth acts on the other object. However, the distance and direction between the mass points and the object are different one another. ..."

(3) "... Ball A, of mass m_1, is on the top of a long table. Another one, Ball B, of mass m_2, approaches at a constant velocity v to and collides with Ball A. If the collision is a perfect elastic collision, then ..."

(4-5) In order to solve some physics problems related to the phenomena around us more effectively, it is sometimes necessary to suppose some assumptions or ideal conditions in order to make the situations simpler. **To solve the problem below effectively, what kinds of assumptions or ideal conditions do you think are needed? (Please, do not solve these problems.)**

(4) As shown in the drawing, a person is pulling a box, of mass M, with a force F. The angle between the force and the floor is θ. What would be the acceleration of the box?

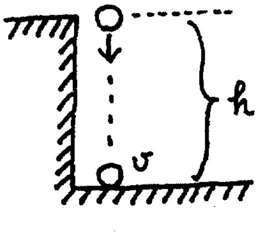


(5) A basketball player is trying to throw a ball to the basket ring. In order to score a goal, with what initial velocity has he have to throw it with the angle of θ with the horizontal plane? The diameter of the ring is R. (Please see the drawing for other factors.)

(6) The following is a typical example of physics problems and their solutions. By examining the given <solution> carefully, **can you explain what kinds of assumptions or idealization were used in the solution?**

<Problem>

A ball is released from the height of h. What would be the speed, v, of the ball when it reaches at the ground?



<Solution>

If the gravitational acceleration is g, $h = 1/2\, gt^2$.

Thus, the time of falling is $t = \sqrt{(2h/g)}$.

The ball accelerates during the falling.

$\therefore\ v = gt = g\sqrt{(2h/g)} = \sqrt{(2gh)}$