Addressing Students' Difficulties in Understanding Two Different Expressions of Gravitational Potential Energy (I) : mgh & -GMm/r

Gyoungho Lee* and Jinseog Yi

Department of Physics Education, Seoul National University,
San56-1, Sillim-dong, Gwanak-gu, Seoul, South Korea
ghlee@snu.ac.kr* colbert0@snu.ac.kr

Abstract. During our investigation of students' understanding of gravitational potential energy, we found some difficulties that students have with this topic. Many students who took upper-level mechanics courses had difficulties in understanding why there are two different expressions of gravitational potential energy. These students said they had some difficulties in understanding why there should be two different signs (+ & —) and two different forms (g & 1/r) even though these expressions were considered as representing the same gravitational potential energy. To gain understanding of the sources of student difficulties, we used weekly reports and individual interviews. We analyzed student difficulties in terms of conceptual knowledge, procedural knowledge, and contextual knowledge. The results of these research have guided the development of teaching material that addresses students' difficulties in understanding gravitational potential energy. We will show the development process and contents of the material in the second paper on this topic [1].

Introduction

Although gravitational force and gravitational potential energy are familiar topics to students from secondary schools, many students have difficulties in understanding these topics [2]. In particular, one of the frequent difficulties stems from the two different expressions of Gravitational Potential Energy (G.P.E): mgh & -GMm/r. Students sometimes pose the question, "Why should there be two different signs (+ & —) and two different forms (g & 1/r) even though we are considering the same gravitational potential energy." In this study, we have tried to understand the sources of the students' difficulties, from three kinds of knowledge perspectives [3]: conceptual knowledge, procedural knowledge, and contextual knowledge.

Research Context

This study took place at Seoul National University, a public university. The student population studied was an upper-level mechanics class of 68 students (2005, 2006 years). The course under investigation was a two-semester course taken by physics education majors who are preservice teachers.

The following data was collected and analyzed during the course of this study:

- weekly report

In 2005~2006, we collected weekly reports from students in the course. In this study, we revised the original weekly report [4]. These weekly reports revealed what students had learned and their difficulties in learning mechanics. We used the following questions in the weekly reports:

1. What do you learn in this week lectures? How could you learn them?

2. What kinds of difficulties do you have in this week lectures? (precisely)

3. Do you have experienced conflicts between your previous knowledge and new knowledge that you have learned in this week.

- Individual interviews

We also conducted individual interviews with three students. The interview questions were based on the weekly reports. It took about 30 minutes with a student, respectively.

Results

Table 1 shows the results of the students' difficulties in learning two different expressions of Gravitational Potential Energy (G.P.E): mgh & -GMm/r. As can be seen, during the 2005-2006 study period, 42.6% students experienced difficulties in understanding the two different expressions of gravitational potential energy (mgh & -GMm/r). There are four sources causing the difficulties: +/- signs, reference point, proportion to r & 1/r, G.P.E graphs.

From the perspective of knowledge structure [3], the sources of difficulties could be divided into

two: conceptual knowledge and procedural knowledge. The 'reference point' is related to conceptual knowledge. On the other hand, '+/- signs, proportion to r & 1/r, G.P.E graphs' are related to procedural knowledge.

Among the 29 students who had difficulties with the topic, the source of difficulties for 41.4% students was related to reference points. They could not understand why we should consider separate reference points for mgh & -GMm/r.

We also found that many students experienced the +/- signs as a source of difficulty. They believe that the sign of energy should be +, if there is energy. Many students are reluctant to admit expressions of energy with zero(0) or minus(-) because they consider existent energy as an ability of working or pushing an object. In addition, students have long been used to representing with a plus(+) as kinetic energy ($\frac{1}{2}mv^2$) or potential energy (mgh) since having learned physics early in their school careers. In other words, students do not understand that the methods of energy expression can be various; for instance, that existent energy can be expressed

TABLE 1. Students' difficulties[29/68 : 42.6%](2005. 3 & 2006. 3)

Difficulties	Sources of difficulties	Examples	Frequency	Percent(%)
mgh vs. $-\frac{GMm}{r}$	+ (Absolute) vs − (relative)	I believe that energy is existent(positive value). How can we use the negative value?	9	31.0
	reference point	How can I decide the sign and the datum point for the algebraic expression?	12	41.4
	r vs $\frac{1}{r}$	Why is the same object of gravitational potential energy represented differently? (proportion or inverse proportion r)	3	10.3
	Different graphs	Are the two graphs different or the same?	5	17.3

with a plus(+) or a minus(-). In an interview, student K said,

"Why can energy expressed with minus sign? If I were a teacher, how would I explain this?.....my concepts.....Since I have been considering this (topic), I have been confused."

Here, the minus sign(-) of universal gravitational potential energy($-\frac{GMm}{r}$) gave rise to difficulty (in other words, cognitive conflict) with the student's belief that, "Energy should be expressed with a plus sign(+)".

In addition, students also had confusion over using absolute zero and relative zero. Generally, we use zero with two concepts. Absolute zero stands for "no existence", meaning "not to be". In contrast, relative zero stands for "comparative reference point": it is the same as a scale of thermometer pointing 0℃. Relative zero depends on the reference point of the relative scale rather than the absolute value of energy existence. For instance, a temperature pointing to 0 does not mean that there is no internal energy. Likewise, potential energy pointing to 0 does not mean that there is no potential energy. Thus, even though potential energy has a minus(-) sign, we can say that it exists. The students' belief that energy should be expressed with a plus(+) obstructs their vision in distinguishing between absolute zero(0) and relative zero(0), providing another reason to be reluctant to accept the minus(-) expression for gravitational potential energy.

The third source of students' difficulties was the different expression of G.P.E as a 'r' function. They thought that the proportion to r is in controversy with the proportion to 1/r. Thus, they could not match the two different expressions of G.P.E. In an interview, student K said,

"Although there is the same gravitational field, why is gravitational potential energy in the surface of th earth not represented with $-\frac{GMm}{r}$ *but with* mgr. *why must we use the expression ' mgr ' in the surface of the earth."*

The last source of students' difficulties was the graphs of G.P.E. Intuitively, it is difficulty to consider them as the graphs that express that G.P.E originated from the same earth.

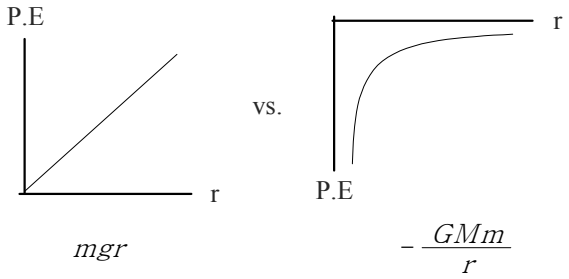

Figure 1. The graphs of mgr and $-\frac{GMm}{r}$

Summary & Future Study

In this study, we found that students' difficulties in understanding two different expressions of Gravitational Potential Energy (mgh & -GMm/r) were the major difficulty in their learning mechanics: 42.6% of students had difficulties with this topic during the two year study period. We also found the sources of difficulties in understanding the two different expressions of Gravitational Potential Energy. These sources were the +/- signs, reference points, the proportion to r & 1/r, and G.P.E graphs. From the perspective of knowledge structure, the 'reference point' is related to conceptual knowledge. On the other hand, '+/- signs, proportion to r & 1/r, and G.P.E graphs' are related to procedural knowledge.

In the future, we intend to probe the resources for addressing the students' difficulties concerning this topic in more detail. Even though this is a preliminary study, the results of this study have guided the development of some new teaching material for resolving students' difficulties in understanding G.P.E. We will report upon the development process and major contents of these materials in our second paper [1] which has the same title submitted to the PERC proceedings.

Acknowledgments

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