Toward Understanding Student Difficulty in Upper-Level Mechanics Problem-Solving Processes*

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Abstract

Over the past decade, many students have been losing their interest in physics. One of the essential reasons why students look away from physics is the fact that they face difficulty in solving physics problems. Since mechanics is a fundamental subject in physics, many researchers have studied how students learn mechanics and solve problems related to mechanics. However, there is little research focusing on the students' specific difficulties in the process of problem solving. This study investigated students' specific difficulties (with the degree of difficulties) and the core sources of these difficulties. 24 university students who majored in physics education participated in this study. We have developed a framework, the House Model (HM), for helping and analyzing students' problem solving. We found that students felt greater difficulty in planning and executing steps than in visualizing, knowing and finding steps. As the problems grew in difficulty, this pattern became more distinct. We found the sources of the students' difficulties and tried to suggest method of helping the students who experience difficulties in problem solving.

Key words: student difficulty, problem-solving, upper-level mechanics, House Model

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Ⅰ. INTRODUCTION

Secondary school students have been losing their interest in physics since the end of the 20C, a time in which enrolment in science and engineering studies lowered. In particular, the numbers of students who select physics in their university entrance examinations has been growing lower and lower. Students often say, "Physics is too difficult to study." This is one of the essential reasons why students are looking away from physics (Williams et al., 2003). Whether students are majoring in physics or not, they have difficulties in solving physics problems. In many cases, despite having the knowledge to solve a problem, students cannot apply this knowledge and therefore fail to solve the problem (Tuminaro & Redish, 2004).

Research into problem solving in physics is a traditional theme as it is a very important issue. Mechanics is a fundamental subject in physics. The importance of mechanics is the reason that a large number of researchers have investigated the issue of solving problems in mechanics. However, many instructors still do not know which processes block the students and where students experience difficulty in solving mechanics problems. We have developed a new framework, the House Model (HM) (Byun et al., 2004), in order to provide guidance for solving of mechanics problems. In this paper, through the use of HM, we have attempted to identify and address difficulties in the problem solving process. We have analyzed student homework and conducted interviews with three students in order to try to locate the source of student difficulty in solving physics problems.

Ⅱ. THEORETICAL BACKGROUND

The studies of problem solving process include using mathematics, strategy (or process) and knowledge structure in the process of solving physics problems (Hsu, 2004). Studies using mathematics start from a point of view that sees mathematics as a language of physics. Redish (2005) said, “Math may be the language of science, but math-in-physics is a distinct dialect of that language.” He also said that using math in physics is not just doing math. The studies about strategy (or process) in problem solving originated in the study of math. Polya (1957) introduced a four-step problem solving process in his paper, ‘How to solve it?’ According to Polya, the four-step processes in solving mathematical problems are the understanding of the problem, devising a plan, carrying out the plan, and looking back. In the case of physics, Larkin (1978) maintained a four-step process: describing the problem, planning a solution, implementation, and checking the result. Recently, Heller illustrated five stages in problem solving: focus on the problem, describe the physics, plan the solution, execute the plan, and evaluate the answer (Heller et al., 1992). Reif (1995) suggested three steps in solving mechanics problems: analyzing the problem, constructing a solution, and checking.

Experts and novices solve problems very differently from each other in solving-procedure and knowledge structures. According to many studies, the experts use ‘knowledge-development’ strategy and the novices use ‘means-end’ or ‘random’ strategy (Simon et al., 1978; Park, 1990). Experts possess much knowledge in the field and their knowledge is chunked together. However novices have little knowledge in the field and their knowledge is split in pieces (Chi et al., 1981).

These studies help us understand some important facts about solving physics problem. Quite a number of these studies depend on interviews and thinking aloud to identify the problem solving process. These methods are appropriate for determining individual characteristics, but are limited in their ability to illustrate entire learners’ processes. These studies did not provide solutions enabling students to have better ability in problem solving. A large number of students still cannot do well in problem solving. Recently, there have been many studies investigating ‘student difficulty’ in learning physics (Schonborn et al., 2002; Reigosa et al., 2007; Lee, 2007; Jeon & Lee, 2007; Yi, 2008; Lee, 2006). These studies have investigated student difficulty in learning physics concepts or in solving physics problems when studying mechanics, electromagnetism and thermal statistics (Yi, 2008; Choi et al., 2007; Ji, 2008). 'Student difficulty' means the psychological condition aroused by students' perceived gap between the present level and the expected level of content, teacher, context and evaluation in a class (Lee, 2006). Although studies on 'student difficulty' are more generalized than before, little research exists on student difficulty in the problem solving process. We have developed a special framework, the House Model (HM), for analyzing student difficulty when solving mechanics problems. We try to determine student specific difficulties in a given step when they solve mechanics problems, and investigate the reasons why students feel difficulties in this step. We also try to determine if any change in patterns of student difficulty exist between easy and challenging problems.

Ⅲ. RESEARCH CONTEXT

A. Methodology

24 university students majoring in physics education and enrolled in an upper-level mechanics class during Semester 1 in 2008 took part in this study. They consisted of 11 sophomores taking the course for the first time and 13 juniors or seniors who had taken the course at least two times. The textbook used for the class was Symon Mechanics (Symon, 1971). The class had two lectures (75min) a week with the professor, and one recitation (60min) a week with three teaching assistants. The professor and the three TAs had a weekly Thursday meeting to analyze student difficulties and determine homework assignments. Every week students had to submit a weekly report (Etkina, 2000) as a homework assignment and solve 4~5 problems. The homework problems included the exercise problems in the textbook (Symon, 1971), calculus-based

introductory physics problems, and new problems created by the instructors.

The homework problems were composed of 2~3 traditional problems, one House Model (HM) problem, and one group problem (Ha, 2009). Every week, we proposed a fresh problem created by the instructors or a difficult exercise problem from the textbook as a HM problem. When students solved a HM problem, they were required to check the degree of student difficulty at each step. During the semester, the total number of HM problems was ten. We analyzed 10~20 students' HM reports (see Fig.1) every week. Through analyzing the HM reports, we identified the student difficulties in the problem solving process. We had originally intended to analyze the students' responses related to the checking step, but lacked sufficient data to do so as many of the students did not rank their level of difficulty for this step. We wanted to answer the question, 'When a student solves a mechanics problem, which step is the most difficult?' To obtain the answer to this question, we utilized the HM and analyzed ten HM problems (122 answers) by ANOVA. Then, we operated Tukey's test for post hoc comparison.

Students were also required to submit an Exercise Self Report as a homework assignment. We investigated the degree of difficulty in solving problems from the Exercise Self Reports; next we calculated the 'overall score of difficulty'. To find out the change of pattern between easy and challenging problems, we divided the problems into two groups by overall score of difficulty, one consisting of the two easiest problems and other consisting of the two most difficult problems among the ten HM problems. We conducted a t-test of the two groups. We find out the relation between the overall score of difficulty and the degree of student difficulty in each step during solving mechanics problem. Finally, we analyzed the weekly reports and Exercise Self Reports. In addition, we interviewed three students (Peter, Kevin, James; these are fictitious names) enrolled in this mechanics class.

B. House Model (HM)

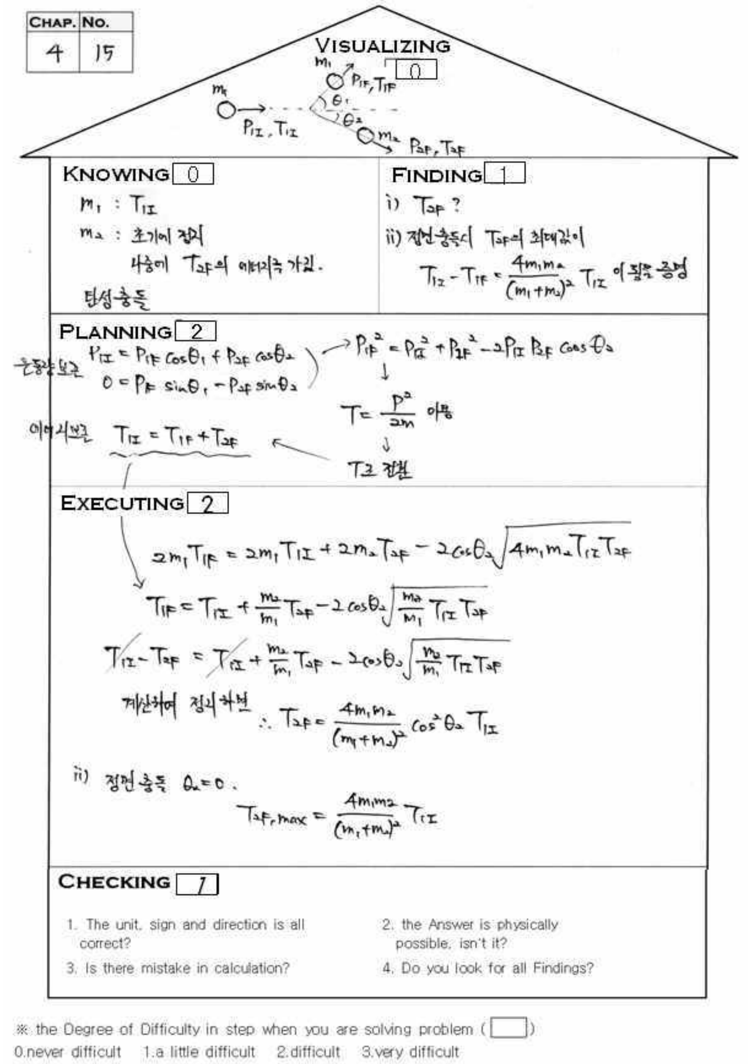

Figure 1. This is an example of a House Model report. The HM is a visual problem solving method. We asked students to rank their degree of student difficulty for each step in the process of solving mechanics problems. For instance, in Figure 1, a student ranked 0 in the difficulty of the visualizing step since he could draw the problem situation. However, he had difficulty (ranked 2) in the planning step.

The House Model (HM) is a new method of physics problem solving that we first developed in 2004 (Byun, 2004). Since 2004 we have been suggesting to our students that when they solve mechanics problems they use the HM frame. The HM has two purposes: (1) to help students solve problems, as a good problem solving model; (2) to help teachers and students to identify which step is causing difficulty for the student. Since students traditionally have felt difficulty in solving mechanics problems, they need a concrete guide. Because previous methods are text-full and mechanical forms, we need a new method to know the entire process of the students' problem solving at a glance. When we developed the HM, we strived for it to have a visualized structure and a natural process.

The HM's order for solving a problem is generally from top to bottom (①Visualizing, ②Knowing, ③Finding, ④Planning, ⑤Executing, ⑥Checking); however, ①~③ are able to be exchanged in order and ④ and ⑤ can be united (see Fig. 1). One of the reasons that we make HM's process order like ①~⑥ is to induce students to solve problem using knowledge-development strategy. As we previously stated, knowledge-development strategy is higher than the other strategies (mean-end and random) in the problem-solving success rate. In visualizing step, students sketch the problem situation and mark factors such as coordinates and force. In the knowing step, students write down the variables and values given in the problem. In the finding step, students confirm the question and find variables or values that the problem requests from them. In the planning step, after students combine several weighty pieces of information from the visualizing, knowing and finding steps, they design a problem-solving strategy. In the executing step, throughout the application of the plan, students conduct calculations and discover the answer. In the checking step, throughout verifying the units, signs and physics adequateness, students confirm the answer.

Since the development of the 1st version of the HM in 2004, we have changed its structure and inner position. The HM in 2008 is the 3rd version of the HM. The motives for this rebuilding of the HM were as follows: (1) The 1st HM had too many steps for solving the problem in the given time. (2) Because of extreme difference with the students' own model, student could not utilize the HM. At first when using the HM, students may experience difficulty and spend much time learning how to use the model; however, we expect that in the end students will become sufficiently familiar with the HM to the point that they will no longer need to be using it by hand, but rather will be comfortably able to use it in their heads. In this study, we used the 3rd version HM. In the HM, we provide a blank for each step for students to check the degree of their difficulty, from 0 (never difficult) to 3 (very difficult).

Ⅳ. RESULTS

A. Degree of student difficulty in the process of problem-solving

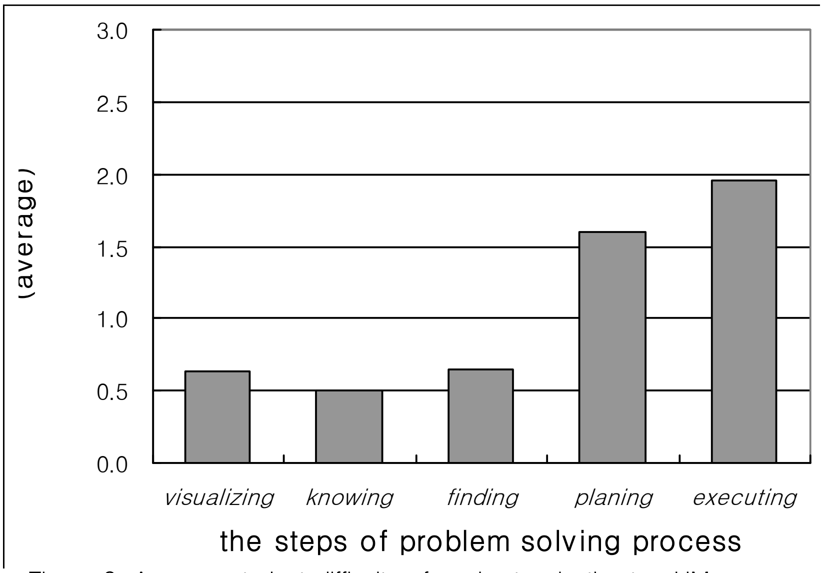

Figure 2. Average student difficulty of each step in the ten HM problems. Difficulty in the executing step is the highest; planning is the second highest. The others represent a similar degree of difficulty (0=never difficult, 1=a little difficult, 2=difficult, 3=very difficult).

Fig. 2 shows the average degree value of student difficulty during each step of the problem solving process. For this result, we analyzed 122 HM reports. As we can see, the executing step is the most difficult step (degree of student difficulty=1.96), and the planning step (degree of student difficulty=1.59) is the second most difficult step. Thus, the student difficulty in visualizing (degree of student difficulty=0.64), knowing (degree of student difficulty=0.50) and finding steps (degree of student difficulty=0.64) are similar and lower than those in executing and planning.

As we analyzed by ANOVA as being $\alpha=.05$, we discovered that differences among student difficulties in the steps are significant. For a more detailed analysis, we conducted Tukey in a Post Hoc test and found the next result: the degree of student difficulty in the executing step is statistically ($\alpha<.05$) higher than in the planning step. The degree of student difficulty in the planning step is statistically ($\alpha<.01$) higher than in the three other steps (visualizing, knowing and finding). The degree of student difficulties in the visualizing, knowing and finding steps are not significant different (=statistically same; $\alpha>.05$).

This result shows that when students solved mechanics problem they could sketch the related situation, gather the needed information and then find the required value. However, even though the students solving an easy problem, they experienced difficulty in devising a plan and calculating mathematically. After we discovered this result (Fig. 1), we wondered, "When students solve problems, differences exist between easy and challenging problems, don't they?" To satisfy our curiosity, we conducted the next piece of research.

B. Comparison of student difficulty between easy and challenging problems

We divided ten HM problems into easy and challenging problems using the 'overall score of difficulty', which is based upon the Exercise Self Report. The value of the overall score of difficulty is determined as follows:

1: I had no problem in solving the problems by myself.
2: I solved the problem by myself, but it took a long time and made me experience difficulties.
3: At first I could not solve the problem by myself, thus I sought for some assistances.
4: There were some helps from others, but I could not solve the problem.

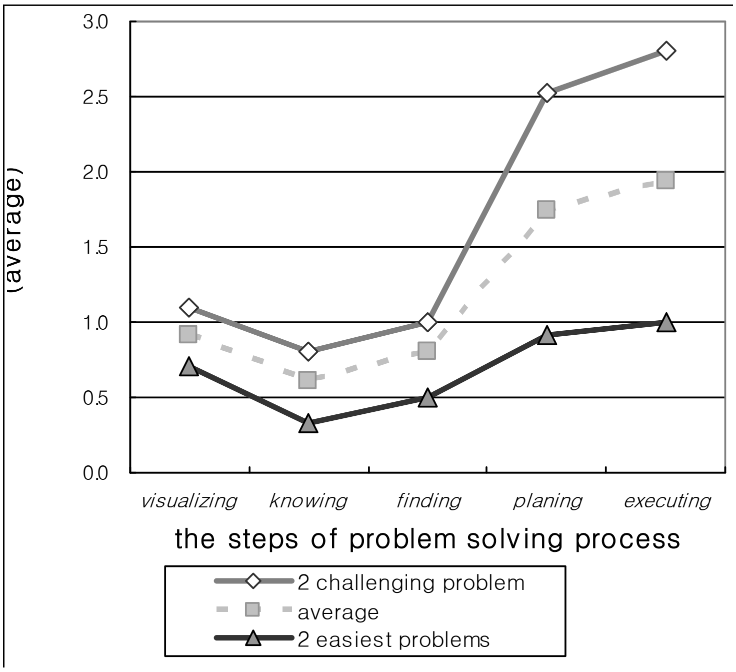

Figure 3. The degree of student difficulty in the process of problem solving. As the problems increase in difficulty, the degree of student difficulty in the planning and executing steps also increases (0=never difficult, 1=a little difficult, 2=difficult, 3=very difficult).

From the overall score of difficulty, we selected the two easiest problems and the two most challenging (=hardest) problems. Fig. 3 shows how the pattern of student difficulty changes between easy and challenging problems. Whether a problem is easy or not, the degree of student difficulty in the visualizing, knowing and finding steps rarely change and, as ever, the planning and executing steps display a high degree of student difficulty. However, as the problems increase in difficulty, the students' difficulties in the planning and executing steps increase. To confirm this result statistically, we conducted a t-test for two groups (easy and challenging problems).

Table 1. A comparison of student difficulty between the 2 easiest problems and the 2 most challenging problems. As we examined t-test in each HM step, we found the statistical difference in planning and executing steps.

HM Step		visualizing	knowing	finding	planning	executing
2 easiest problem n=30	**mean**	**0.63**	**0.33**	**0.50**	**0.93**	**1.00**
	std. dev	0.67	0.48	0.68	0.74	0.74
2 most challenging problem n=20	**mean**	**1.10**	**0.75**	**0.90**	**2.50**	**2.80**
	std. dev	0.85	0.97	0.91	0.95	0.52
Difference		**0.57**	**0.42**	**0.40**	**1.57**	**1.80**
sig.		0.035*	.086	.082	.000**	.000**

As the t-testing shows (Table I), the difference in student difficulty in the executing step was 1.80, which shows the largest value among the differences between all of the steps. The difference in student difficulty in planning was 1.57. The difference of student difficulty in the visualizing step (0.57) was less than both the executing (1.80) and the planning (1.57) steps, but the difference in the visualizing step shows significant difference, too. On the other hand, the difference in student difficulty in the knowing and finding steps do not represent significant value.

C. A case study on student difficulty with the House Model

We selected four HM problems, each with 'overall score of difficulty' higher than 3. Many of the students could not solve these four problems by themselves. Among these four HM problems, we picked out two problems in which the problem's theme was different. In addition, throughout a student's HM report, Exercise Self Report, weekly report and three student interviews (especially for the 8^{th} week HM problem), we surveyed the sources of student difficulty.

The 3^{rd} week HM problem (Symon ch.2 #38)

A freely rolling freight car weighing 104 kg arrives at the end of its track with a speed of 2m/sec. At the end of the track is a snubber consisting of a firmly anchored spring with k=1.6x104kg/sec2. The car compresses the spring. If the friction is proportional to the velocity, find the damping constant bc for critical damping. Sketch the motion x(t) and find the maximum distance by which the spring is compressed (for b=bc). Show that if b≥bc, the car will come to a stop, but if b≥bc, the car will rebound and roll back down the track.

Figure 4. The 3^{rd} week HM problem is challenging. Many students failed in solving this problem. Overall score of difficulty=3.11

The 3^{rd} week HM problem asks us how the damped oscillator operates (see Fig. 4). The 3^{rd} week HM problem was one of the two problems that we considered to be challenging. Many students who were enrolled in our mechanics class failed to solve this problem at first (overall score of difficulty is 3.11). However, after these students were helped by their classmates, they were able to solve this problem. Externally this problem consists of only one problem, but in substance this problem actually consists of four sub-problems. To solve this problem, students were good at utilizing differential equations. As shown in the result of student difficulty, the planning (1.58) and executing (2.50) steps are higher than the other steps. In the

Exercise Self Reports, the students told us 'The Planning of the solving process is difficult.', 'I had difficulty applying the right equation to spring motion situation.', 'I couldn't solve the differential equation.', and 'The calculations were too complex to carry out.' Their words indicate the sources that planning step and the executing step are difficult.

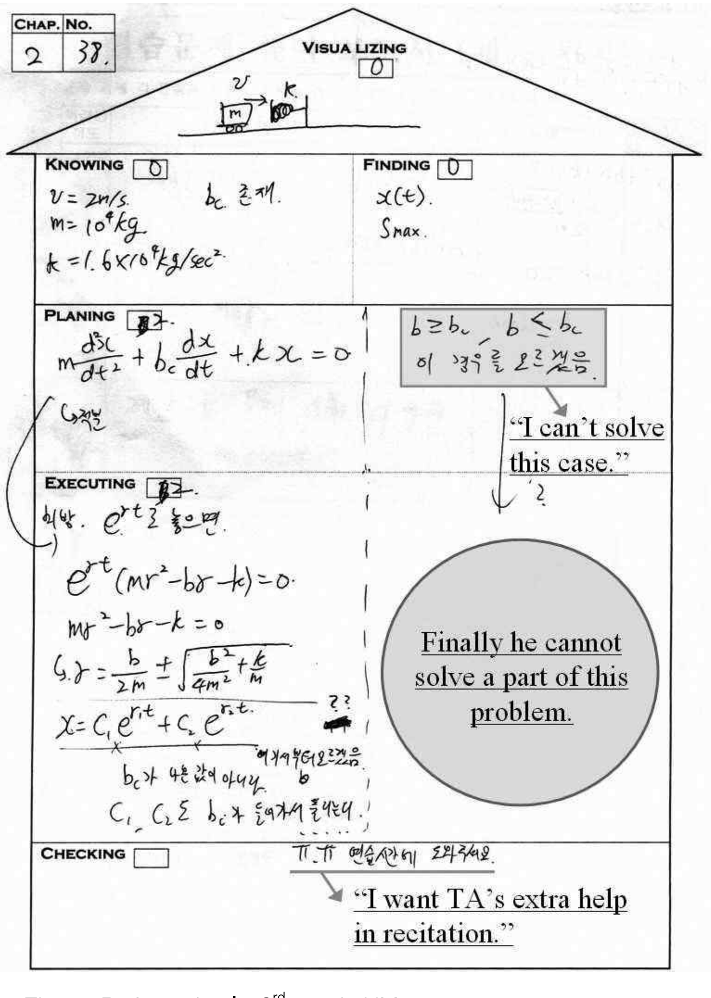

Figure 5. A student's 3rd week HM report

Fig. 5 displays a student's HM report on the 3rd week problem. He represented student difficulty as follows: visualizing

(0), knowing (0), finding (0), planning (2) and executing (2). We can acquire important information from his HM report. An examination of the roof zone (the visualizing, knowing and finding steps) reveals that the student understood problem situation. In fact, his degree of student difficulty in these steps is zero. However, an examination of the planning step shows the information: he could make the differential equation, but he could not devise a plan in the $b \geq bc$ and $b \leq bc$ cases. Thus, when in the executing step he was unable to continue solving the problem, he asked the TA for extra help. Overall, he knew the given information, the problem's demands and the fact that he had to use a differential equation. In spite of this knowledge, he failed to solve the problem because he did not know solving strategy for the specific case in question.

The 8^{th} week HM problem (Symon ch.3 #57)

a) Discuss the types of motion that can occur for a central force

$$F(r) = -\frac{K}{r^2} + \frac{K'}{r^3}$$

assume that K>0, and consider both signs for K'

b) Solve the orbital equation, and show that the bounded orbits have the form (if $L^2 > -mK'$)

$$r = \frac{a(1-\epsilon^2)}{1+\epsilon cos\alpha\theta}$$

c) Show that this is a precessing ellipse, determine the angular velocity of precession, and state whether the precession is in the same or in the opposite direction to the orbital angular velocity.

Figure 6. 8^{th} week HM problem. Most of the students felt difficulty in solving this problem; overall score of difficulty=3.53

The 8^{th} week HM problem (see Fig.5) was one of the most challenging problems; the overall score of difficulty is 3.53. To solve this problem, a student had to know the physical concept of central force and be able to utilize differential calculus in a quadratic curve. Although students learned parts of quadratic curve theory, such as the concept of an eclipse, in high school, most of the students had no experience in explaining quadratic curve through the use of mathematics.

The reason why this problem is so difficult is the fact that we interviewed three participants who had been enrolled our upper-level mechanics in that semester. The three interviewees (Peter, Kevin, James) said that they could not easily solve this problem. As a result, they searched for helpful textbooks or asked classmates for help.

James checked his difficulties as follows: visualizing (3), knowing (2), finding (3), planning (3) and executing (3). James said,

> *"I don't understand well the central force and effective potential. I could not understand the problem situation."*

In the visualizing step, he drew a graph, but as can be seen in Fig. 7, the form of graph is not delicate. In the finding step he could not interpret the meaning of problem c). Thus, student difficulties in visualizing and finding steps are quite high (3). In the planning step he could devise plans for problems a) and b), but marked a '?' character for problem c). Although Fig. 7 might not show us the executing part of his HM report, he could not solve problem c) during the executing step, either.

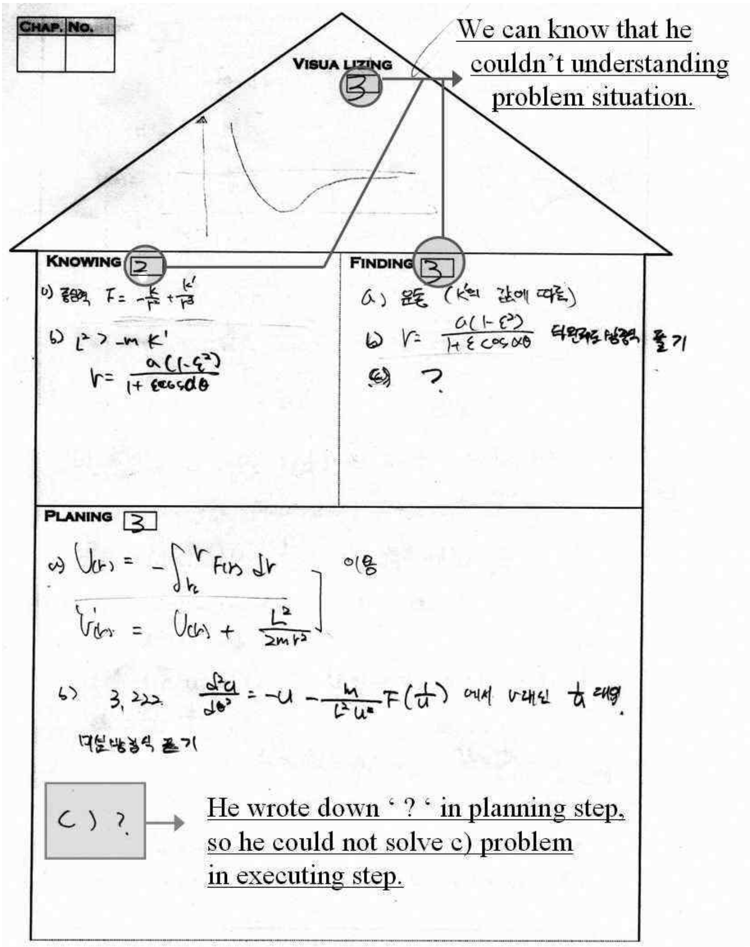

Figure 7. The 8th week HM report of James's HM report. His HM report consists of two pages. One is this page; the other parts (executing and checking) were recorded in next pages.

Peter checked his difficulties as follows: visualizing (0), knowing (0), finding (0), planning (2), and executing (2). Peter said,

"The process to find a proper equation is difficult. Even after solving this problem, I don't know its physical meaning."

Kevin checked his difficulties as follows: visualizing (0), knowing (0), finding (1), planning (2) and executing (2). Kevin remarked,

> *"It is too difficult for me to substitute a variable in the differential equation."*

From the two cases (3-week and 8-week HM problem), we could see that a student's HM report is highly related to his interview or Exercise Self Report. Furthermore, we could recognize the source of student difficulty. We will deal with these sources in the next section.

D. The sources of student difficulty in the process of solving mechanics problem

Through interviews with the three students and analysis of the weekly reports and Exercise Self Reports (see Result C.), we identified three sources of student difficulty.

The first source of student difficulty is a lack of mathematical skill. In this type, students said that they felt difficulty in the executing step. Through analyzing individual interviews, the Exercise Self Reports and the weekly reports, we found that most of the students had difficulty understanding the differential equations and approximations used on the Taylor or Fourier series. Since the students did not learn these mathematical skills until university, they were not adept at utilizing these skills. In an upper-level mechanics course, challenging problems require high-level mathematical technique and strong ability at calculating complex equations. Therefore, as problems become more difficult, the level of student difficulty in the executing step is higher.

The second source of student difficulty is a lack of specific physics knowledge necessary for solving a given problem. Specific physics knowledge means the theory, concepts, and equations that we need to solve a problem. In addition, we have to add solving experience to specific physics knowledge. In this type, students said that they experienced difficulty in the planning step. Some students did not possess the necessary physics concepts for solving a mechanics problem. For example, forced harmonic equation, orbital motion and effective potential theory belongs to this category. Regardless of the fact that some other students possessed the required physics knowledge, the students in this type could not connect their previous knowledge to a particular problem situation. In practice, there are very often cases where a student has no experience solving problems related to this content.

The last source of student difficulty is a lack of understanding of the problem situation. In this type, students said that they felt difficulty in the visualizing, knowing and finding steps. Some of the students could not process the visualizing step until they understood the conditions and ascertained a proper representation. Some of them did not know the physics terms being used or could not interpret the problem text because of poor English ability. In our study, since most of the participants were relatively strong in their command of physics and English, few students experienced difficulty in these steps.

So we compared these sources with student difficulties in each step (Fig.3), Most of students experienced a lack of mathematical skill, and had physics knowledge insufficiently. Some students could not understand problem situation.

V. SUMMARY AND IMPLICATIONS

For one semester, we offered students ten House Model (HM) problems as homework. With the object of analyzing difficulty in the problem solving process, we collected HM reports, Exercise Self Reports and weekly reports from the students, and we interviewed three of the students. When the students in the study tried solving a mechanics problem, they experienced difficulty. As analyzing via HM we found that: they felt the greatest amount of difficulty in the executing step and the second greatest amount of difficulty in the planning step. Moreover, they felt that the visualizing, knowing and finding steps were easier than the executing and planning steps. Whether a problem was easy or not, this pattern is maintained (see Fig. 3). However, as the problems became more challenging, difficulties in the planning and executing steps increased.

The case study involving the identification of student difficulties (which was composed two HM problems), revealed that a student's HM report was highly related to his interview or Exercise Self Report. In addition, the case study showed that these sources of student difficulty are related to the types of student difficulty experienced the HM steps. The first source of student difficulty is a lack of mathematical skill. In this type, students have difficulty in the executing step. The second source of student difficulty is a lack of physics knowledge related to the problem. In this type, students experience difficulty in the planning step. The last source of student difficulty is a lack of understanding of the problem situation. In this type, students have difficulty in the visualizing, knowing and finding steps.

This study is in a preliminary stage. However, the result of this study suggests basic ideas for identifying and addressing student difficulties in the problem solving process. Further research needs to include more extensive analyses of collected data and greater explorations of student responses to the HM. Such study would enable us to design new approaches for addressing the difficulties that students experience when trying to solve upper-level physics problems.

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